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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN ENGINEERING PROFESSIONS, TRADES, AND VOCATIONAL OCCUPATIONS OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED

LOCOMOTIVE BOILERS
HAND FIRING OF LOCOMOTIVES
BOILER ATTACHMENTS
HEAT AND STEAM
THE LOCOMOTIVE

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY
1924

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed. At the end of the volume will be found a complete index, so that any subject treated can be quickly found.

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LOCOMOTIVE BOILERS
(PART 1)

CONSTRUCTION, DETAILS, AND MAINTENANCE

DEVELOPMENT

1. The development of the locomotive boiler during the past 50 years has been a remarkable achievement. In the 70's, the boilers then in use were of the narrow-firebox type, with the size of the firebox limited to the distance between the frames and the driving wheels. Boilers of this type had a heating surface of about 1,000 square feet, heating surface meaning the surface exposed to the heat of the fire or the hot gases. In the 80's the foundation ring was raised and widened so that it would set on the frames, and the width of the firebox was increased so that it would just clear the driving wheels on each side. This increase in grate area led to an increase in the size of the boiler, and the heating surface was increased in proportion, or to 1,800 to 1,900 square feet. The next step was to place the firebox back of the driving wheels and to increase the width so that it would extend out over the wheels, provided they were of comparatively small diameter. If they were not, a pair of wheels of small diameter, called trailing wheels, was placed under the firebox to distribute more equally the weight of the boiler on the wheels.

2. By this arrangement it was possible to have a firebox of a width limited to the clearance of the right of way, and a length limited to the ability of the fireman to shovel the coal.

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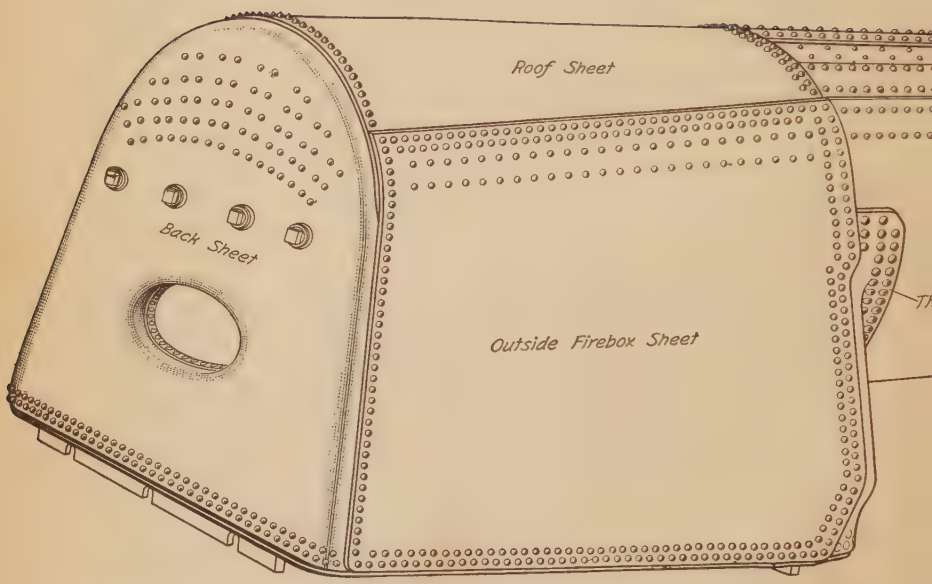
With the adoption of fireboxes of these dimensions, the other parts of the boiler were also increased in size. The cylindrical portion was increased from about 50 inches in diameter to nearly 120 inches as at present with the largest type of locomotives. The tubes were also lengthened from 10 or 12 feet to 18 or 19 feet, and in the boilers of large Mallet engines up to 25 feet.

The increase in the length and diameter of locomotive boilers resulted in an increase in the heating surface, which now ranges from 1,500 to 8,500 square feet. The steam pressure of 100 pounds to 110 pounds per square inch which was used in the 70's was increased to from 130 pounds to 160 pounds to the square inch in the 80's. From that time, the pressure was gradually increased until about 1900, when a pressure of 200 pounds per square inch became common. Pressures of 210 and 250 pounds are in use on some railroads, but the practice is not general, the predominating pressure being from 180 pounds to 200 pounds per square inch.

3. The increase in the size and capacity of locomotive boilers would not be possible were it not for the firebrick arch, the superheater, and the mechanical stoker. The firebrick arch, by reason of its position in the firebox, increases the length of the path of the hot gases through the firebox, thereby insuring better burning of the gases generated during combustion and an increase in the efficiency of the firebox heating surfaces. The superheater heats the steam to a higher temperature after it leaves the boiler, and thereby increases the volume of the steam that is delivered to the cylinders by about 30 per cent. The employment of a superheater permits the use of a boiler of smaller size when the cylinder volume remains the same, or, with a boiler of the same size, an increase of 30 per cent. in cylinder capacity may be obtained as compared with a saturated-steam locomotive. By the use of a superheater, the size of the boiler which otherwise would be very bulky is kept within reasonable limits. Without a superheater, the average locomotive when working very hard would necessitate the boiler being forced beyond its economical capacity. The



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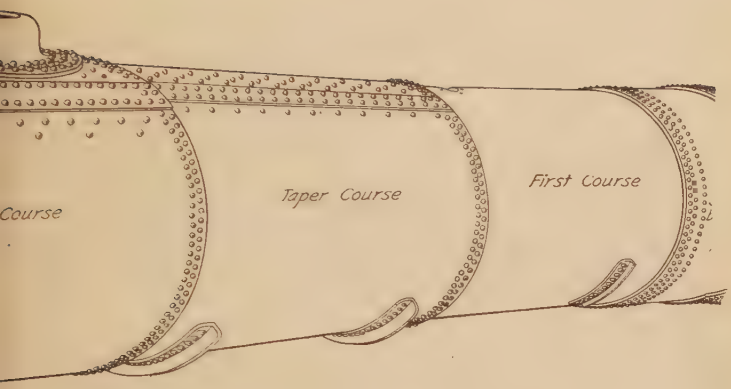
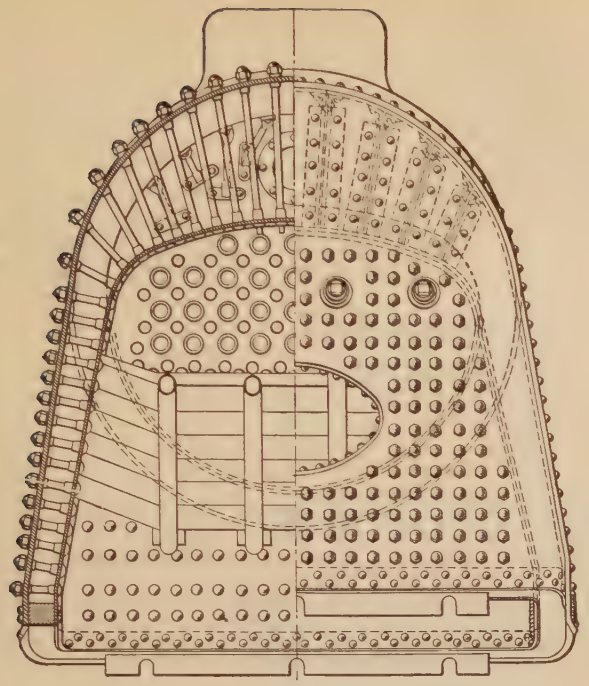

Course
Taper Course
First Course



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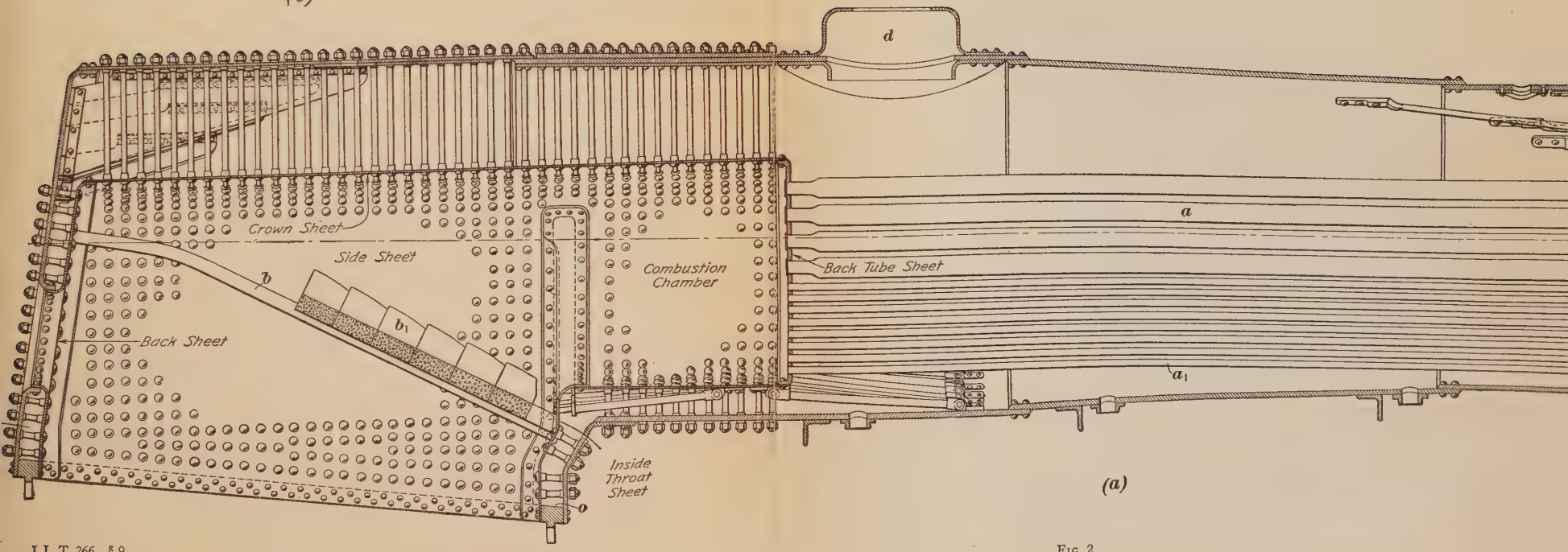

(a)

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FIG. 2

mechanical stoker, which is a device for mechanically firing a boiler, enables a sufficient quantity of coal to be placed in the firebox to develop the full capacity of the boiler. This device is especially adapted to boilers that have a very large grate area such as are used with the Mikado, Santa Fe, and Mallet types of locomotives

GENERAL DESCRIPTION

4. Definition.—The locomotive boiler consists of a steel shell for containing water which is converted into steam by the heat of the fire in the firebox and furnishes the energy to move the locomotive. Locomotive boilers are of the internal multitublar fire-tube type. This means that the firebox is contained within the boiler, and that the boiler contains a large number of tubes and flues.

5. Names of Exterior Sheets.—An exterior view of a modern type of locomotive boiler is shown in Fig. 1. The exterior sheets of a boiler consist of the back sheet or head, the roof sheet, the outside firebox sheet (one on each side), the throat sheet, the dome course, the taper course, the first course, the smokebox and shell ring, and the smokebox.

On very long boilers, a course known as the second course is sometimes introduced between the taper course and the first course; with boilers having combustion chambers, a combustion-chamber course is placed next to the roof sheet, instead of the dome course. Sometimes the dome is placed on the combustion-chamber course, this course then being a dome course or a combustion-chamber course. The roof sheet and the two outside firebox sheets may be made in one piece instead of three as shown in Fig. 1. The taper course may have a uniform taper all the way around, in which case it is referred to as the conical course; a taper course is really one in which the taper is on the upper part, the lower part being straight. The dome course and the combustion-chamber course are sometimes made in one piece.

6. Names of Interior Sheets.—The interior sheets of a locomotive boiler are shown named in Fig. 2 (*a*) and are as

follows: The front tube-sheet, the back tube-sheet, the crown sheet, the two side sheets, the back sheet or door sheet, and the inside throat sheet. This latter sheet is only necessary in boilers having combustion chambers. With the exception of the front tube-sheet, the sheets just named combined with the grates form the firebox. The grates serve to hold the fuel while it is being consumed.

7. The back and the front tube-sheets are connected by the superheater flues a and the small tubes a_1. The flues and tubes

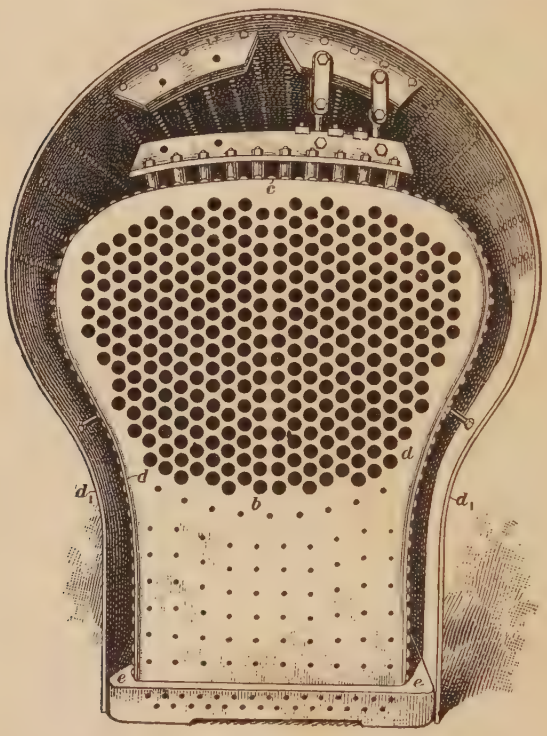


FIG. 3

serve to convey the smoke and gases from the firebox to the smokebox and also act as stays for the sheets. The inside of the firebox sheets and the tubes and flues are covered with water when the boiler is fired up, as these parts are exposed to

the heat of the fire on the opposite side. The smokebox or extension front end c contains the exhaust nozzle (not shown) and also certain draft appliances, by means of which an even draft is produced through all parts of the fire. The steam dome d is a receptable for collecting and holding dry steam and also forms a convenient place for the throttle valve. The combustion chamber is an enlargement of the firebox and is used to promote combustion. The arch tubes b, four being generally used, aid the circulation of the water and also serve to support the brick arch b_1.

The outside of the boiler is covered by a lagging to prevent the loss of heat by radiation. The lagging is usually composed of some substance that will not burn, and which is also a poor conductor of heat, such as magnesia and asbestos. The lagging is applied in sections and is covered with a sheet-iron jacket. Boilers were formerly lagged with wood.

8. Interior View of Boiler.—Fig. 3 is a view of a boiler with the throat sheet and the dome course removed, and therefore shows the position of the firebox sheets with respect to the outer sheets of the boiler. This view shows the outer sides, or the water sides, of the firebox sheets with the exception of the back sheet which is at the rear and cannot be seen. The back tube-sheet is marked b, the crown sheet, c, and the firebox side sheets, d. The firebox is, then, a box or compartment within the larger compartment formed by the roof sheet, the outside firebox sheets, and the back sheet. The lower parts of the side sheets d and the outside firebox sheets d_1 are riveted to the wrought-iron or steel frame e, called the foundation ring or the mud ring. The space that is formed by the firebox side sheet d, the mud ring e, and the outside firebox sheet d_1 is called the water leg.

9. Throat Sheet.—As shown in Fig. 1, the shape of the upper part of the dome course conforms more or less to the shape of the roof sheet and these two parts can therefore be easily connected together. However, to connect the lower cylindrical part of the boiler to the side sheets requires a sheet of special shape, which is called the throat sheet, one

side of which is shown in Fig. 4. The bottom part *e* of the throat sheet is flanged so as to conform to the cylindrical shape of the part of the boiler which rests on and is riveted to it.

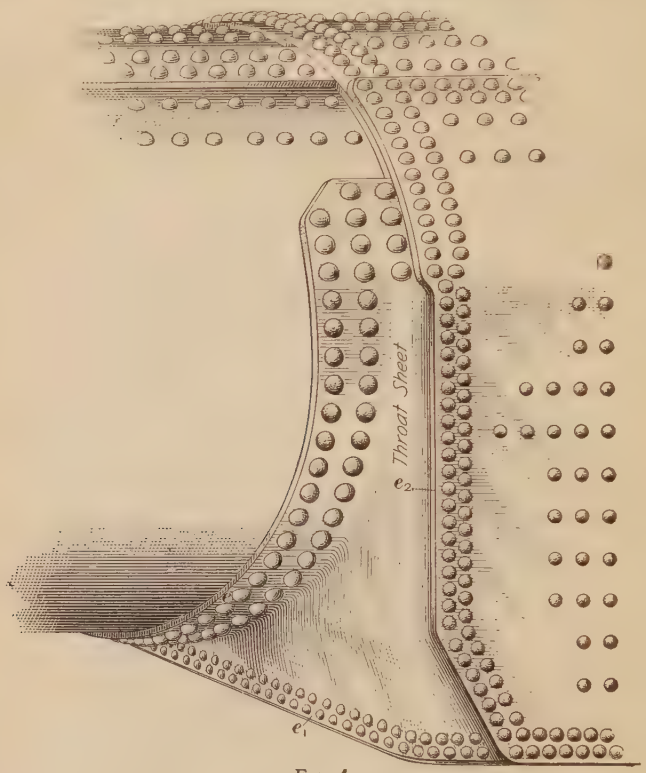


FIG. 4

The sheet is flat where it is riveted to the outside firebox sheets. In some designs, the throat sheet extends entirely around the boiler and therefore connects the entire cylindrical shell with the roof sheet and firebox side sheets.

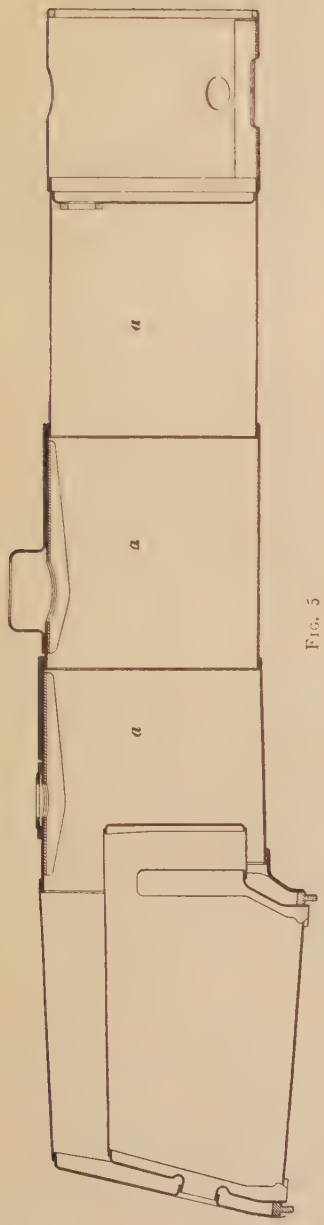


FIG. 5

CLASSIFICATION OF BOILERS

10. Names of Classes.—Locomotive boilers are classified according to their shape and also according to the shape of the firebox. Classified according to shape, boilers are known as straight-top, wagon-top, extended wagon-top, and conical. If the shape of the firebox is considered, locomotive boilers are referred to as narrow-firebox, wide-firebox, Belpaire-firebox, oil-burning-firebox, Jacobs-Shubert-firebox, etc.

A narrow-firebox boiler is one in which the firebox is placed between the frames, and its width thereby restricted to the space between them. With a wide-firebox boiler, the firebox is wider than the frames, and is placed on top of them. All modern locomotive boilers have wide fireboxes, because sufficient grate area must be provided to burn the required amount of coal, and thereby develop full boiler capacity without the rate of combustion being excessive. The illustrations that follow show boilers with wide fireboxes.

11. Straight-Top Boiler. A section taken through a straight-top boiler is shown in Fig. 5. A straight-top boiler is one in which

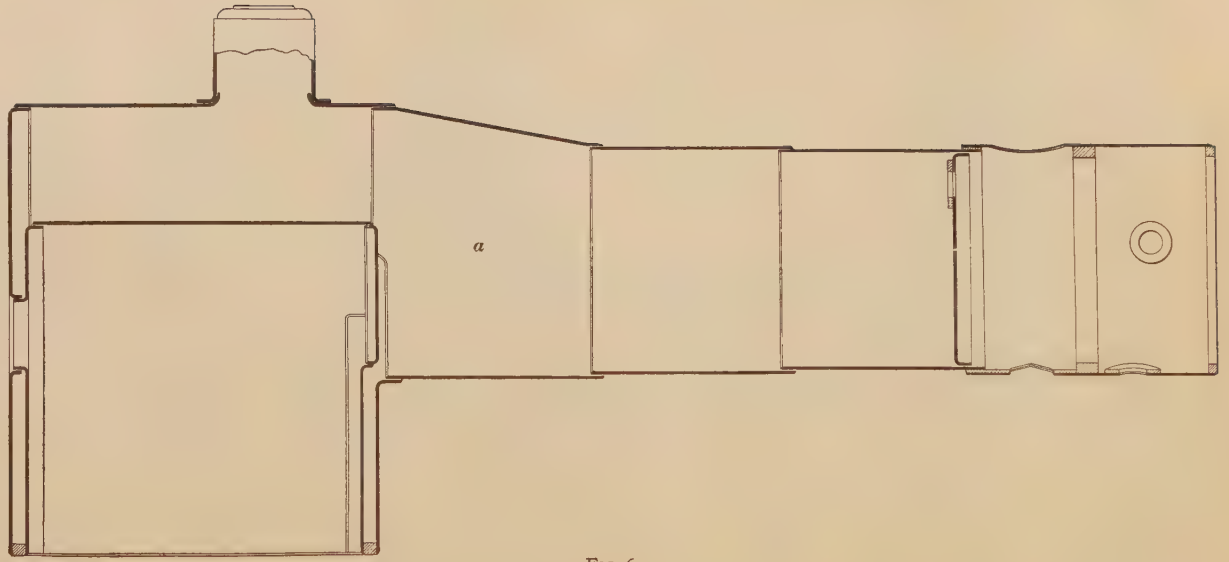


Fig. 6

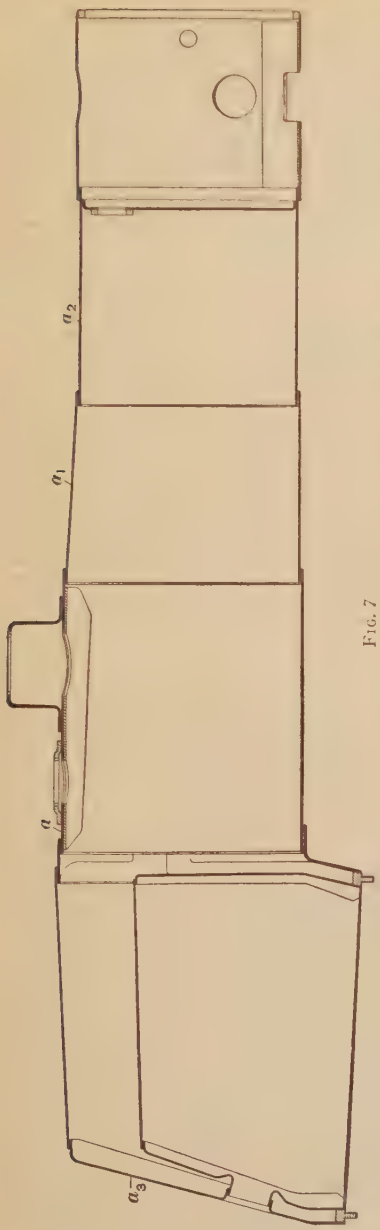


Fig. 7

the cylindrical courses a are of uniform diameter. In some designs, the roof sheet slopes toward the back head, as shown.

12. Wagon-Top Boiler. A sectional view of a wagon-top boiler is given in Fig. 6. This type of boiler has the sloping course a in front of the roof sheet. The steam dome is usually over the firebox, or it may be placed in the sloping course. This type of boiler is no longer in general use.

13. Extended Wagon-Top Boiler.—An extended wagon-top boiler, Fig. 7, is one which has one or more cylindrical courses a next to the roof sheet, a conical course a_1 which tapers down to a smaller diameter, the taper being confined to the top and sides, and one or more cylindrical courses a_2 of reduced diameter next to the smokebox. The cylindrical course a is placed next to the firebox so as to provide a place for the steam dome ahead of the firebox and thus do away with the crown-bar method of staying the crown sheet, which is employed with the wagon-top type. The

construction of the back head a_3 may be either vertical or sloping forwards, depending on the size of the boiler. In small boilers, the back sheet is usually vertical. In large boilers, the sheet slopes forwards as shown in Fig. 7, so that the upper portion will not take up so much room in the cab.

14. Conical Boiler.—The difference between an extended wagon-top boiler and a conical boiler is in the shape of the tapering course a_1, Fig. 7. With a conical boiler, the taper extends all the way around the boiler, while with the extended wagon-top, the taper is restricted to the top and sides.

CONSTRUCTION OF BOILER SHELL

JOINTS AND SEAMS

15. Definition.—The boiler shell comprises all the exterior sheets of the boiler and therefore consists of the cylindrical courses in front of the firebox, and the roof sheet, back head, throat sheet, front tube-sheet, and the outside firebox sheets. However, boilermakers refer to the part between the firebox and the smokebox as the boiler shell, and the other exterior sheets as the outer firebox sheets. As shown in Fig. 1, the shell forward of the firebox is made up of courses, and these vary in number according to the length of the boiler.

16. Girth Joints.—The cylindrical part of the boiler shell encloses the tubes and flues, and is so arranged that the course of smallest diameter is placed next to the smokebox. The joints at the junction of the courses are called girth, or transverse, joints or seams. The courses are generally lap-jointed together; that is, the end of one course laps over the end of the course next to it and the two are riveted together. One, two, or three rows of rivets may be used, depending on the size of the boiler. When two rows of rivets are used, the joint is referred to as a double-riveted lap joint. The dome course and the first course, Fig. 1, are connected to the taper

course by double-riveted lap joints. A triple-riveted lap joint is one in which three rows of rivets are used.

17. Details of Girth Seam.—In Fig. 8 (*a*) is shown an exterior view of a triple-riveted lap joint, between a taper course and a dome course and view (*b*) is a sectional view. The taper course *a*, view (*b*), fits on the inside of the dome course *b*, and the two are held together by three rows of rivets *c*, which are driven by hydraulic pressure to a full head on each side. When there are two or more rows of rivets in a lap joint, it is preferable to place the rivets in alternate rows as shown in view (*a*). At *d*, view (*b*), is shown a recess in the edge of the plate, which is made by calking it to insure a steam-tight joint. The calking should be done with a blunt round-nose tool held in a pneumatic hammer, care being taken that the plates are not sprung apart in the process of calking. Both the inside and the outside edges are sometimes calked to insure a more uniform job.

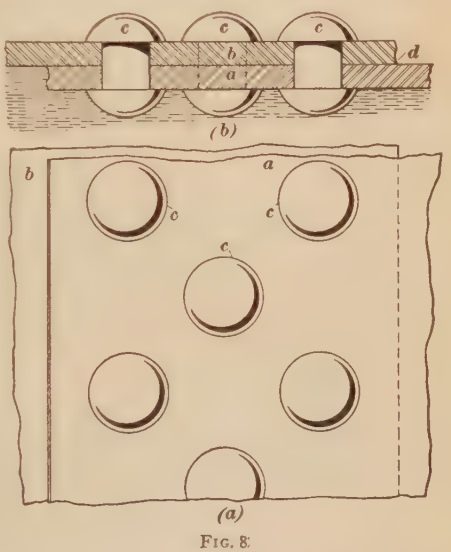


FIG. 8

18. Butt Joints.—The courses that comprise the cylindrical part of a boiler are usually made in one piece. When the ends of the course are connected together, the seam will come lengthwise of the boiler as shown in Fig. 1. The kind of joint which is used to connect the ends of a course together is called a butt joint, because the ends butt together and do not overlap as with the girth joints.

19. Details of Butt Joint.—An exterior view of a butt joint is shown in Fig. 9 (*a*), and view (*b*) is a sectional view.

As shown in view (*b*), the ends *a* of the course are brought together but not overlapped, and stripes, or welts, *b* and *c* which cover the joint are then riveted to the plate on the inside and on the outside.

In view (*a*) the width of the inside welt is the distance between *x* and *y*, and the width of the outside welt is the distance between x_1 and y_1. The dotted line x_2 y_2 shows where the ends of the course meet. The name applied to a butt joint depends on the number of rows of rivets used on each side of the junction of the ends of the course and also on the number of welts. In Fig. 9, three rows of rivets are placed on each side

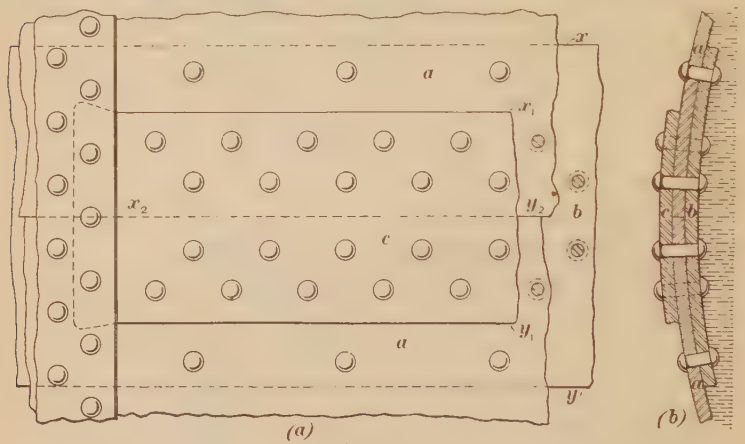


FIG. 9

of the line x_2 y_2, and as two welts are used the joint is referred to as a triple-riveted, double-welt, butt joint. A quadruple-riveted double-welt butt joint is one in which four rows of rivets and two welts are used, and a quintuple-riveted double-welt butt joint is one which employs five rows of rivets on each side of the seam and has two welts.

In the construction of a butt joint the object should be to obtain a form of joint that has as near as possible a strength equal to that of the solid plate. The form of joint shown in Fig. 9 has a strength equal to about 90 per cent. of the solid plate and it is therefore said to have an efficiency of 90 per cent.

20. Relative Stresses on Girth and Lengthwise Joints.—Calculations show that a seam running lengthwise of a boiler is subject to nearly twice the stress that acts upon a girth joint in the same boiler; therefore a joint running lengthwise of the boiler will withstand only one-half the boiler pressure that will be withstood by a girth joint of the same construction. For this reason, care should be taken that lengthwise seams shall be properly constructed to withstand the pressures and stresses to which they are subject. It should be remembered that in addition to the fact that the girth joint is subject to only half the stress, it is also strengthened by the staying properties of the tubes and flues and by the stays that connect the front and back heads of the boiler.

FIREBOX AND SMOKEBOX JOINTS

21. Back Head and Roof Sheet.—The back head *a*, Fig. 10, is connected to the roof sheet *b* by a single-riveted lap joint, which is calked at *c*. A single row of rivets has been found sufficient to carry the strain on the head, on account of the way the head is stayed at other points. The portion of the back head below the crown sheet is rigidly stayed to the back sheet and the foundation ring. Above the crown sheet, the back head is stayed to the roof sheet by diagonal braces similar to those shown at *c* in Fig. 11. Therefore the greater part of the load on the back head is carried by the staybolts and braces. Fig. 11 illustrates how the part of the front tube-sheet above the tubes and flues is braced. The back ends of braces *c* are connected by pins *d* to the T irons *e* riveted to the tube-sheet. The front end of the brace is flattened out sufficiently to allow two or three rivets to be used to connect it to the first course.

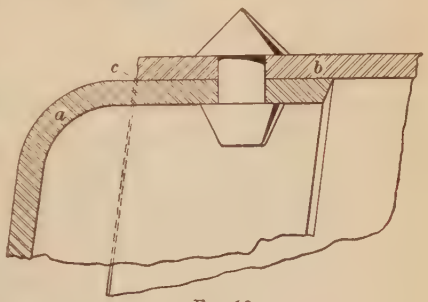


FIG. 10

22. Front Tube-Sheet.—In Fig. 12 is shown how the front tube-sheet m is connected to the first course n by a

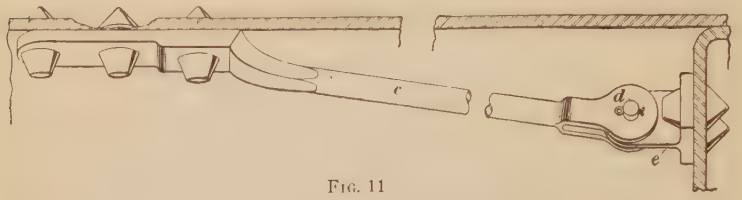


FIG. 11

single row of rivets which pass through the flange of the sheet and the outer course. The rivets o are sometimes driven slightly flattened as shown and sometimes with a flat head on both sides. The first method is the better as it makes it easier to use the tube expanders on the side rows of tubes, and also to calk the rivets should they leak.

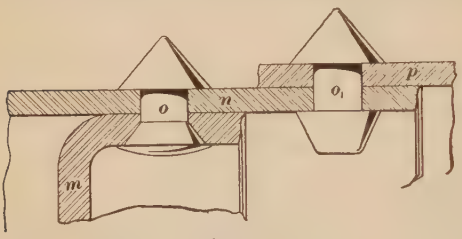


FIG. 12

23. Smokebox and First Course. Fig. 12 shows that the smokebox p is connected to an extension of the first course n beyond the tube-sheet m, by a single or double row of rivets o_1. The smokebox may be riveted directly to the course n as shown in Fig. 12, or a wrought iron ring n_1, Fig. 13, called

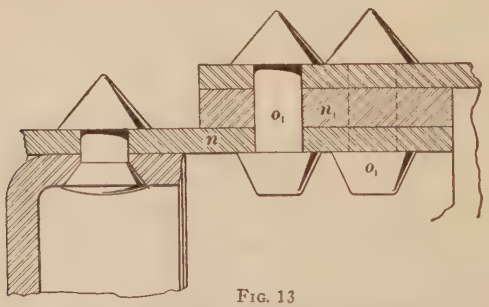


FIG. 13

the smokebox ring, may be inserted between the course n and the smokebox. The ring provides a stopping point for the

insulation that is applied to the outside of the boiler. Two rows of rivets o_1 are generally used with the ring n_1.

24. Dome Course and Roof Sheet.—The dome course, or the combustion chamber course, as the case may be, is connected to the roof sheet in the same way as the cylindrical courses are connected together. That is, if the cylindrical courses are connected together by double-riveted lap joints, the same construction is used at the junction of the dome course with the roof sheet. The joint extends down as shown in Fig. 4, until it meets a similar type of joint in the throat sheet and side sheets.

25. Throat Sheet and Side Sheets.—As shown in Fig. 4, the throat sheet is connected to the side sheets and the cylindrical course by a double-riveted lap joint, but in some cases the connection is made by a triple-riveted lap joint.

THE SMOKEBOX

26. Purpose.—The smokebox, or front end *c*, Fig. 2, as it is commonly called is the forward part of the boiler, into which the products of combustion pass through the tubes, and from which they are discharged to the stack. The smokebox serves as a receptacle to collect the solid particles of fuel that are drawn through the tubes by the force of the exhaust. It provides a space in which the steam pipes, exhaust nozzle, and superheater arrangement, if any, can be placed and inspected, and it also permits of the installation of the draft appliances.

The size of the smokebox is not a matter of very great importance, except that a large one modifies the effect of the exhaust on the fire, while a small one has a very marked effect on the fire. In America, the generally accepted length of smokebox is between 5 and 7 feet. This length is considered as being the most desirable, as it gives a uniformly distributed draft over the entire fire and at the same time provides ample room for the draft appliances.

GENERAL ARRANGEMENT OF SMOKEBOXES

27. Factors Affecting Arrangement.—The arrangement of the smokebox, which means the arrangement of the appliances within it, ranks among the most important details of locomotive-boiler design. On account of the importance of the arrangement, together with the wide range of variables that must be taken into consideration, there is as yet no standard construction that is acknowledged to be the one that will produce the highest efficiency of the boiler under all conditions. Among the variables that affect the smokebox arrangement are the following: The different arrangement of arches, the grate area, the percentage of the openings in the grates, the arrangement of the ash-pan air inlets, and dampers, the kind of fuel, the size of the boiler, the length of the tubes, and whether the locomotive uses saturated or superheated steam. One arrangement representative of the practice on locomotives using saturated steam, and one that is representative of the practice with superheated steam, will be described.

28. Arrangement for Saturated Steam.—The general arrangement of the smokebox appliances with a saturated-steam locomotive is shown in Fig. 14, one side of the smokebox being broken away so that the interior parts can be seen. In this figure, c is the smokebox; c_1, the front tube-sheet; c_2, the first course; c_3, the stack; c_4, the exhaust pipe; c_5, the exhaust nozzle; c_6, the steam pipes; c_7, the diaphragm; c_8, the table plate, shown partly broken away; c_9, the diaphragm apron or damper; c_{10}, the netting; c_{11}, the trap door; c_{12}, the petticoat; c_{13}, the smokebox front ring; c_{14}, the smokebox front; c_{15}, the smokebox door; c_{16}, the smokebox and shell ring.

29. The diaphragm plate c_7 deflects the smoke and products of combustion downwards and tends to equalize the draft through the tubes. It is connected at the bottom to the table plate c_8 by means of an angle iron a. The table plate c_8 is placed on a level with the top of the exhaust pipe c_4. The plates b are placed around the steam pipes c_6, so as to make the joints where the pipes pass through the plates c_8 practically

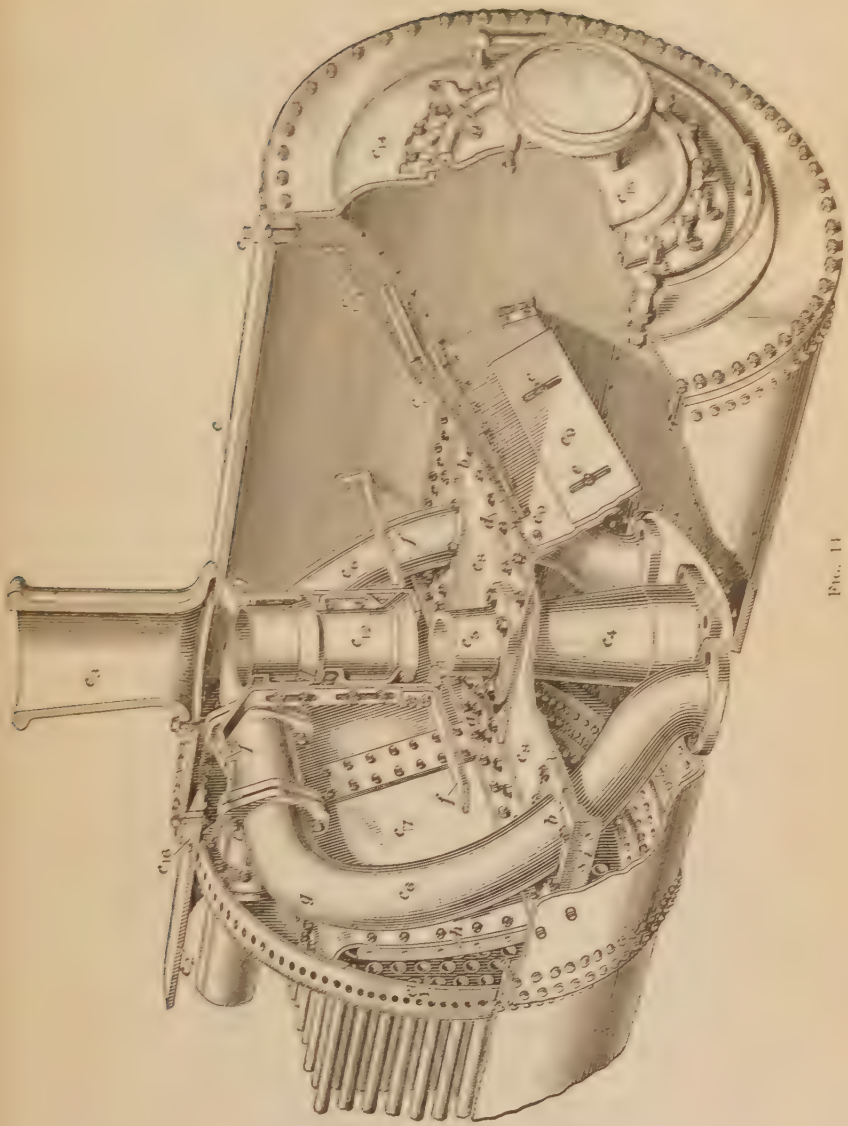


Fig. 11

air-tight. The exhaust then cannot pull live cinders through and set fires along the right of way. The apron or damper c_9 and the netting c_{10} are secured to the table plate by an angle iron d. The petticoat pipe c_{12} is supported on each side by brackets f which are bolted to the smokebox. The arrangement of the petticoat pipe is such as to permit either one of the pipes to be raised or lowered.

30. The diaphragm apron or damper c_9 is set at an angle forwards as shown, and the lower part is made adjustable, so that the draft can be equalized if the diaphragm c_7 does not do it. The object of inclining the damper forwards is to prevent as far as possible the obstruction to the flow of gases that would be caused by sharp angles. The netting c_{10} extends from the table plate upwards as shown. An opening in the netting is closed by the door c_{11}. This door permits repairs to be made to the steam pipes or the petticoat and also permits cleaning out of the cinders. The smokebox front c_{14} is bolted to the ring c_{13}, and the joint between these parts must be absolutely air-tight. The smokebox door is hinged to the smokebox front and is held closed by clamps.

31. Smokebox Arrangement for Superheated Steam.—A smokebox designed for locomotives that use superheated steam is shown in Fig. 15. In this view, one side of the smokebox is shown broken away and part of the netting and plates are removed so that the arrangement may be more clearly seen. The general principle of this type of front end is the same as for a saturated-steam locomotive. However no petticoat pipes are used and some of the plates are placed differently. The stack extends downwards into the smokebox, the base being a short distance above the nozzle c_5. Instead of the diaphragm plate c_7 being inclined as in Fig. 14, this plate, Fig. 15, is placed vertically and directly in front of the superheater header R, and is attached to it by bolts and lugs.

32. The plate, which is made in three sections, extends downwards to a point level with or slightly below the bottom of the superheater flues a and connects to the horizontal table plates c_8. These plates extend from the front tube-sheet c_1

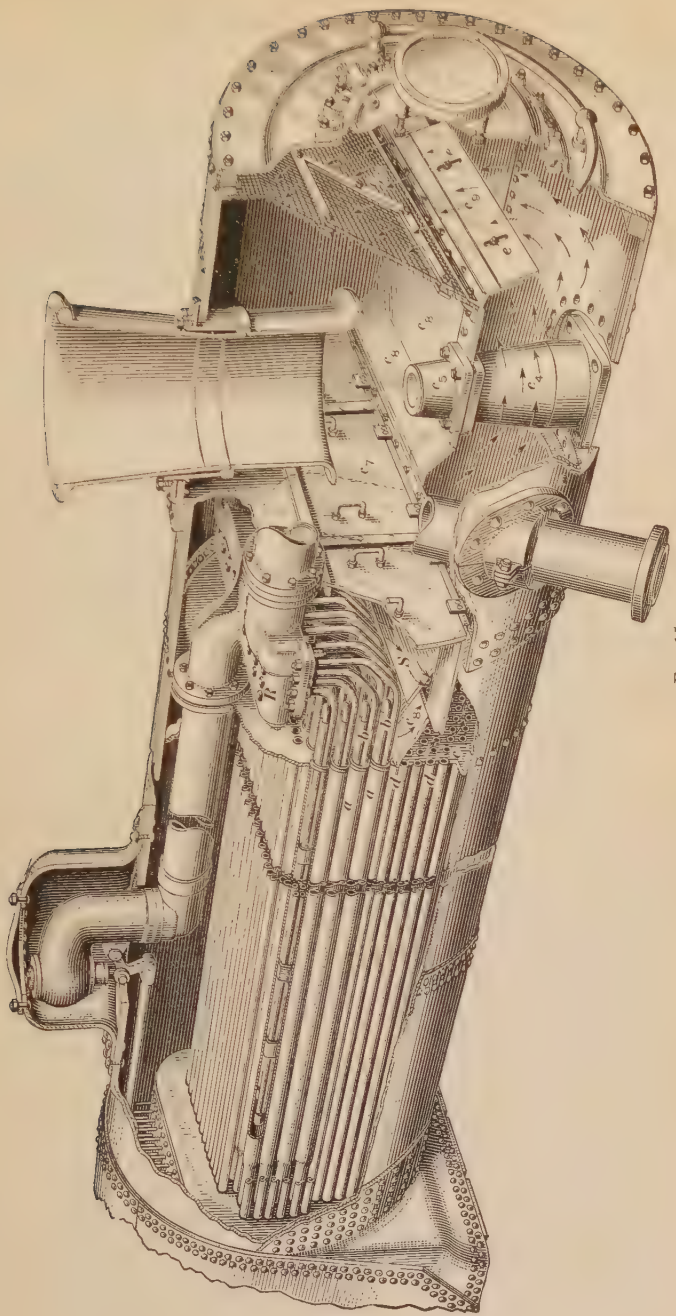


Fig. 15

to a point beyond the exhaust pipe c_4. A movable damper S is placed at a convenient location in the table plate. The damper is so arranged that it opens and closes automatically with the throttle. The damper when open as shown should be at an angle of 60° to the vertical, as this position offers the least obstruction to the flow of gases. The purpose of the damper is to prevent the smoke and the hot gases from passing through the superheater flues when the engine is not working steam. As no steam passes through the superheater units b when the throttle is closed, the units would become overheated and leak if a damper was not used to prevent the flow of gases through the flues a. When the damper is closed, the part of the smokebox that contains the superheater units is boxed off from the action of the draft, but the passage of the gases through the tubes d is not affected. The netting c_{10} and the diaphragm apron or damper c_9 are placed somewhat the same as with a saturated-steam locomotive, these parts being secured to the table plate c_8. The damper can be raised or lowered by slacking off on the nuts e.

DETAILS OF SMOKEBOX ARRANGEMENTS

33. Diaphragm.—The purpose of the diaphragm c_7, Figs. 14 and 15, is to equalize the draft through the tubes and therefore through the fire and to deflect the gases and cinders down into the front end. The diaphragm is usually made in two sections as shown in Fig. 14 and is bolted at the top to an angle iron g on the front tube-sheet just above the top row of tubes. The diaphragm is connected to the side of the smokebox by an angle iron h, one on each side. The bottom of the plate is connected by an angle iron a to the table plate c_8. Diaphragms of the shape shown in Fig. 14 are used on saturated-steam locomotives only.

34. When a superheater is used, the diaphgram c_7 is placed vertical as shown in Fig. 15, directly in front of the superheater header R. This plate is made in three or four sections, depending upon the size of the boiler. The two

sections at the sides are bolted to the header and to angle irons on the side of the smokebox. The two center sections are made removable so that they can be taken off when necessary to inspect or make repairs to the superheater units.

35. Table Plates.—The table plates c_8, Figs 14 and 15, are used to throw the sparks downwards and toward the front of the smokebox. They are fastened to the diaphragm plate c_7 by an angle iron a and to angle irons i, Fig. 14, on the sides of the smokebox. The plates are connected to the exhaust pipe at the center usually by inserting them between the exhaust pipe c_4 and the nozzle c_5. They are held securely by the same bolts that hold the nozzle to the pipe. In some cases the table plates instead of being horizontal, slope slightly downwards as shown in Fig. 15.

36. Diaphragm Apron.—The diaphragm apron, or damper c_9, Figs. 14 and 15, is located at the front of the table plates c_8. It is made in two parts, the upper part being bolted to an angle iron and therefore fixed, but the lower part is adjustable. This part is made adjustable so that it can be raised or lowered when necessary to equalize the draft through the tubes. This is provided for by slotting the apron for the bolts e which hold it to the part of the plate which is fixed. The apron may be placed vertical or it may be placed at an angle, as shown in Figs. 14 and 15. When placed at an angle it offers less resistance to the passage of the smoke. The apron should be of such dimensions that when it is lowered as far as it will go the area of the opening beneath it will be 63 to 68 per cent. of the total cross-sectional area of the tubes. The adjustment of the apron is a matter of local practice, as the quality of the fuel used may affect the steaming of the locomotive and require an adjustment to suit. Also each class of locomotive, and in some cases each individual engine, may require a different adjustment. The diaphragm, the apron, and the table plates really constitute the deflector, or draft plates, of a locomotive smokebox. The netting, the petticoat pipe, and the long stack are for the purpose of adding to the efficiency of the draft appliances.

37. Action of Apron.—The action of the apron c_9, Figs. 14 and 15, is as follows: Lowering the apron causes the draft to be stronger through the lower rows of tubes, and checks flow somewhat through the upper rows. This causes the fire to burn better on the forward part of the grates or next to the tube-sheet. Raising the apron, reduces the force of the draft through the lower rows of tubes and strengthens the draft through the upper rows, and the fire will therefore burn better on the rear grates or next to the door. Unless care is taken in the adjustment, the apron may be located so as to obstruct the flow of the gases, in which event it would be a hindrance rather than a help to the free steaming of the locomotive. If the apron is placed too close to the front tube-sheet, the draft will be seriously restricted and the locomotive will be termed "hot at the door," that is the draft will be so weak that soot will accumulate on the fire-door.

38. Netting.—The netting c_{10}, Figs. 14 and 15, extends upwards from the point where the table plate c_8, and the apron c_9 meet, to the top and front of the smokebox. Its purpose is to prevent any large sparks from being pulled through from the firebox and thrown out of the stack by the action of the exhaust. The netting consists of a network of wires about $\frac{1}{8}$ inch in diameter, with a mesh of about $\frac{3}{16}$ to $\frac{1}{4}$ inch square, or the netting may consist of a perforated steel plate. The netting is held in position by bolting it to the table plate c_8 and to angle irons on the sides and top of the smokebox, or it may be bolted to a piece of plate which extends down a short distance from the top of the smokebox. The total area of the openings in the netting should if possible be equal to or greater than the total tube area of the boiler.

The netting obstructs the flow of gases to such an extent that the size of the nozzle must be decreased slightly to produce the same amount of draft that would be obtained if no netting were used.

39. Petticoat Pipe.—Two views of the petticoat pipe c_{12}, Fig. 14, are given in Fig. 16 (*a*) and (*b*). The petticoat pipe consists of two pieces of pipe, each belled out slightly at the

bottom as shown. The upper part is called the sleeve and the lower part the petticoat. These parts, view (*a*), are bolted to the bracket c_{18} which is used to secure them to the smokebox. As shown in view (*b*) the holes for the bolts c_{19} in the bracket are slotted, and therefore either of the pipes can be raised or lowered. The petticoat pipe was originally designed for locomotives with short front ends or smokeboxes, and served the purpose of equalizing the draft through the tubes. It was therefore made adjustable as shown. With modern locomotives, the only function of the petticoat pipe is to

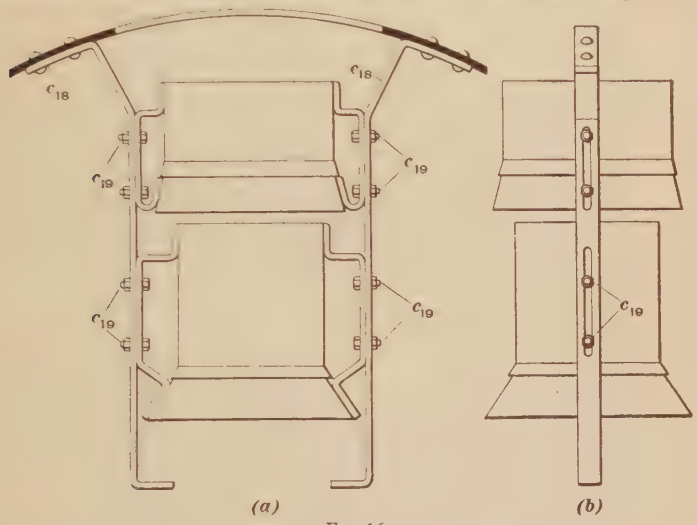


FIG. 16

increase the length of the stack, and thereby confine the smoke and gases within the pipe so that the exhaust has a better chance of giving them an upward motion. As the petticoat pipe is really an extension of the stack, it is usually more convenient to do away with the pipe and extend the stack down into the smokebox instead.

When a petticoat pipe is used, the recommended practice is to fit it on tight to the base of the stack directly in line with the center of the stack, and make it non-adjustable. If the center of the pipe is out of line with the center of the stack the efficiency of the exhaust jet is lowered.

40. Exhaust Pipe.—The exhaust pipe c_4, Figs. 14 and 15, is made of cast iron and is used to conduct the exhaust steam from the cylinders to a proper point in the smokebox. A sectional view of an exhaust pipe with the exhaust nozzle c_5 bolted to it is shown in Fig. 17 (*a*); (*b*) is a top view of the nozzle c_5 and view (*c*) shows the bottom of the exhaust pipe. The exhaust pipe is bolted to the cylinder casting at a point directly over the exhaust cavities and is so placed as to be directly under the center of the stack. The exhaust cavities in the cylinder casting are separate from each other and this necessitates that a partition or bridge p be placed across the exhaust pipe so as to correspond with the partition in the casting. The partition should extend up in the pipe a short distance. The exterior of the exhaust pipe is usually rectangular in shape at the bottom, and gradually changes shape until at the top it is nearly circular.

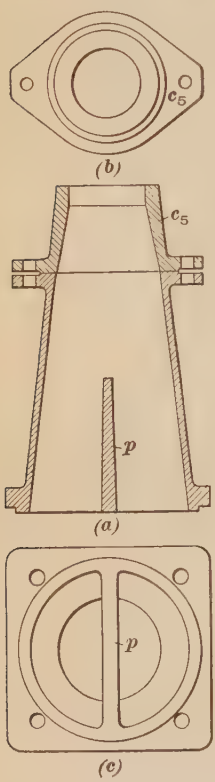


FIG. 17

41. The opening at the bottom, Fig. 17 (*c*), is circular and gradually tapers to the exit, view (*a*), leaving a length of about 1 inch straight at the top. The exhaust pipe should be as short as possible with a proper arrangement of the diaphragm and netting, provided this does not make it less than 19 inches high. Should there be any cause for a reduction in the area of the exhaust opening, the reduction should always be made at the nozzle c_5 and not in the pipe. In a double exhaust pipe, as shown in Fig. 18, the partition p extends up to the top of the pipe. On account of the arrangement of the partition, this type requires a double exhaust nozzle; that is, one with two separate openings, as shown in view (*d*).

42. Exhaust Nozzle.—The exhaust nozzle c_5, Figs. 17 (*b*) and 18 (*d*) is the end piece which is bolted to the exhaust pipe. The opening through the nozzle should be of such a size as to cause the steam which passes through it to produce the desired draft on the fire. If the exhaust nozzle is unduly contracted, the force of the exhaust steam will be extremely violent, and holes will be torn in the fire. A contracted nozzle will also increase the back pressure in the cylinders. If the nozzle is too large, the draft will be too weak, and the required amount of fuel will not be burned.

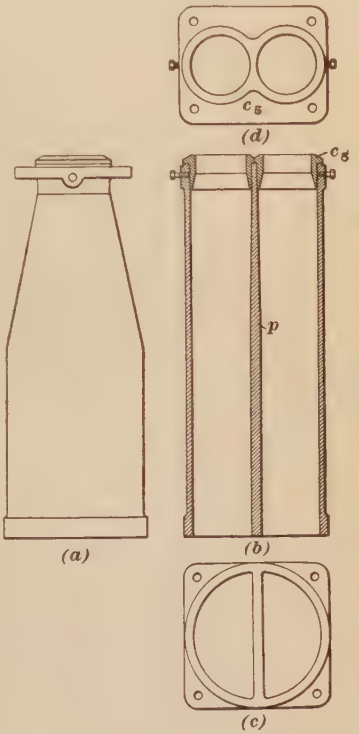
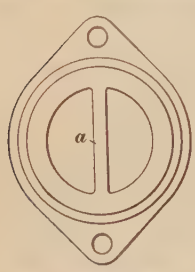


FIG. 18

43. The size of the nozzle varies widely and depends on the size and capacity of the locomotive, the quality of the fuel and the rate at which it is burned, the size of the cylinders, the length of the tubes, and the arrangement of the front-end appliances. With large cylinders, a greater volume of steam passes through the nozzle at each exhaust and the nozzle must therefore be larger than when the cylinders are smaller. If the rate of combustion is high, a contracted nozzle is necessary so that it will create a stronger draft and thereby draw a larger volume of air through the firebox. In locomotives of large capacity with tubes ranging in length from 20 feet to 25 feet, a stronger draft is necessary to pull the hot gases through the tubes so that the rate of evaporation per square foot will not be reduced. This condition requires a reduction in the area of the exhaust nozzle.

44. With such a wide range of variables, it is impossible to have one size of nozzle that is adapted to all conditions of service. Numerous attempts have been made to design an exhaust nozzle the opening through which could be varied to suit the different conditions. A number of variable exhaust nozzles have been tried out, but as yet none has proved worthy of general application.



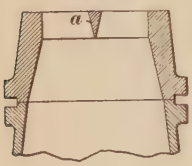


FIG. 19

45. Special Nozzles.—Recent experiments and tests have demonstrated that the circular form of exhaust nozzle does not give the best results in regard to the highest vacuum in the smokebox and the least back pressure in the cylinders. The general practice has been to use circular nozzles, but special-shaped nozzles or those having special attachments are coming into more general use. Among the more effective forms are the *splitter*, and the *four-internal-projection*.

The *splitter nozzle*, Fig. 19, is one that has a circular inlet, which tapers for about $2\frac{5}{8}$ inches, and then is straight to the top or tip. Across the top is fitted a triangular piece *a* with the edge directed downwards and having a width of $\frac{3}{8}$ inch at the top.

The *four-internal-projection nozzle*, Fig. 20, is a circular nozzle which has triangular-shaped bars *a* projecting 1 inch toward the center from four equally distant points on the edge.

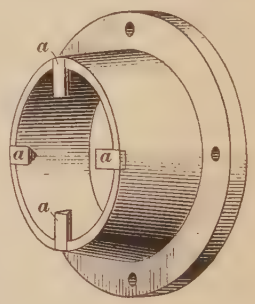


FIG. 20

46. Nozzles for Mallet Locomotives.—With Mallet locomotives, which have two sets of cylinders, the exhaust pipe and nozzle are arranged as shown in Fig. 21, in which (*a*) is a top view and (*b*) a sectional view. The arrangement is really two separate pipes one on the inside of the other, and permits one nozzle to do the work of

two. When the engine is working compound, the exhaust steam from all the cylinders passes through the nozzle a; when working simple, the exhaust from the low-pressure cylinders passes through the nozzle a, and from the high pressure cylinders through the nozzle b. The blower pipe is marked a_1; the steam from the blower passes through the projections a_3.

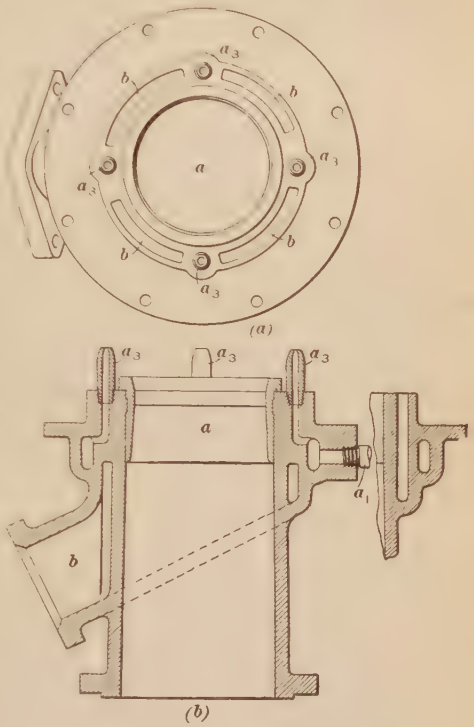


Fig. 21

47. Diameter of Exhaust Nozzle. The American Locomotive Company determines the diameter of the exhaust nozzle by multiplying the diameter of the cylinder by a certain factor, .25, .177, etc., which is found under the heading *Single Nozzle* or *Double Nozzle* in Table I, which shows the standard practice of that company.

This table shows the diameter of the exhaust nozzles for two-cylinder and four-cylinder locomotives burning soft and hard coal and using saturated or superheated steam. The diameter of the cylinders ranges from 18 inches to 32 inches.

The length of the stroke and the steam pressure are not taken into account when considering the size of the exhaust nozzle. The practice of the American Locomotive Company is to use single nozzles, without bridges, for soft coal, oil, and lignite, and double circular nozzles for hard coal. If a bridge

is specified, but the size of the nozzle is not given, a nozzle of larger diameter is used to preserve the net area given in the table. The nozzles for oil-burning locomotives are from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch larger than for soft-coal-burning locomotives of the same cylinder diameter.

The following example illustrates how the diameter of the nozzles shown in Table I is obtained: Let it be assumed that

TABLE I

EXHAUST-NOZZLE SIZES

Diameter of Cylinder (High-Pressure When Compound) Inches	Simple Two-Cylinder								Compound Four-Cylinder (Mallet)			
	Soft Coal				Hard Coal				Soft Coal			
	Saturated		Superheated		Saturated		Superheated		Saturated		Superheated	
	Single Nozzle	Double Nozzle	Single Nozzle	Double Nozzle	Single Nozzle	Double Nozzle	Single Nozzle	Double Nozzle	Single Nozzle	Double Nozzle	Single Nozzle	Double Nozzle
	Factor .25	Factor .177	Factor .225	Factor .159	Factor .23	Factor .163	Factor .207	Factor .147	Factor .325	Factor .230	Factor .293	Factor .207
18	$4\frac{1}{2}$	$3\frac{3}{16}$	$4\frac{1}{16}$	$2\frac{7}{8}$	$4\frac{1}{8}$	$2\frac{15}{16}$	$3\frac{3}{4}$	$2\frac{5}{8}$	$5\frac{7}{8}$	$4\frac{1}{8}$	$5\frac{1}{4}$	$3\frac{3}{4}$
19	$4\frac{3}{4}$	$3\frac{3}{8}$	$4\frac{1}{4}$	3	$4\frac{3}{8}$	$3\frac{1}{8}$	$3\frac{15}{16}$	$2\frac{13}{16}$	$6\frac{3}{16}$	$4\frac{3}{8}$	$5\frac{9}{16}$	$3\frac{15}{16}$
20	5	$3\frac{1}{2}$	$4\frac{1}{2}$	$3\frac{3}{16}$	$4\frac{5}{8}$	$3\frac{1}{4}$	$4\frac{1}{8}$	$2\frac{15}{16}$	$6\frac{1}{2}$	$4\frac{5}{8}$	$5\frac{7}{8}$	$4\frac{1}{8}$
21	$5\frac{1}{4}$	$3\frac{11}{16}$	$4\frac{3}{4}$	$3\frac{5}{16}$	$4\frac{7}{8}$	$3\frac{7}{16}$	$4\frac{3}{8}$	$3\frac{1}{16}$	$6\frac{13}{16}$	$4\frac{13}{16}$	$6\frac{1}{8}$	$4\frac{3}{8}$
22	$5\frac{1}{2}$	$3\frac{7}{8}$	5	$3\frac{1}{2}$	$5\frac{1}{16}$	$3\frac{5}{8}$	$4\frac{9}{16}$	$3\frac{1}{4}$	$7\frac{1}{8}$	$5\frac{1}{16}$	$6\frac{7}{16}$	$4\frac{9}{16}$
23	$5\frac{3}{4}$	$4\frac{1}{16}$	$5\frac{3}{16}$	$3\frac{5}{8}$	$5\frac{5}{16}$	$3\frac{3}{4}$	$4\frac{3}{4}$	$3\frac{3}{8}$	$7\frac{1}{2}$	$5\frac{5}{16}$	$6\frac{3}{4}$	$4\frac{3}{4}$
24	6	$4\frac{1}{4}$	$5\frac{7}{16}$	$3\frac{13}{16}$	$5\frac{1}{2}$	$3\frac{7}{8}$	$4\frac{15}{16}$	$3\frac{1}{2}$	$7\frac{13}{16}$	$5\frac{1}{2}$	$7\frac{1}{16}$	$4\frac{15}{16}$
25	$6\frac{1}{4}$	$4\frac{3}{8}$	$5\frac{5}{8}$	4	$5\frac{3}{4}$	$4\frac{1}{16}$	$5\frac{3}{16}$	$3\frac{11}{16}$	$8\frac{1}{8}$	$5\frac{3}{4}$	$7\frac{5}{16}$	$5\frac{3}{16}$
26	$6\frac{1}{2}$	$4\frac{9}{16}$	$5\frac{7}{8}$	$4\frac{1}{8}$	6	$4\frac{1}{4}$	$5\frac{3}{8}$	$3\frac{13}{16}$	$8\frac{7}{16}$	6	$7\frac{5}{8}$	$5\frac{3}{8}$
27	$6\frac{3}{4}$	$4\frac{3}{4}$	$6\frac{1}{8}$	$4\frac{5}{16}$	$6\frac{1}{4}$	$4\frac{7}{16}$	$5\frac{9}{16}$	4	$8\frac{3}{4}$	$6\frac{3}{16}$	$7\frac{15}{16}$	$5\frac{9}{16}$
28	7	$4\frac{15}{16}$	$6\frac{5}{16}$	$4\frac{7}{16}$	$6\frac{7}{16}$	$4\frac{9}{16}$	$5\frac{13}{16}$	$4\frac{1}{8}$	$9\frac{1}{8}$	$6\frac{7}{16}$	$8\frac{3}{16}$	$5\frac{13}{16}$
29	$7\frac{1}{4}$	$5\frac{1}{8}$	$6\frac{1}{2}$	$4\frac{5}{8}$	$6\frac{11}{16}$	$4\frac{3}{4}$	6	$4\frac{1}{4}$	$9\frac{7}{16}$	$6\frac{11}{16}$	$8\frac{1}{2}$	6
30	$7\frac{1}{2}$	$5\frac{5}{16}$	$6\frac{3}{4}$	$4\frac{3}{4}$	$6\frac{7}{8}$	$4\frac{7}{8}$	$6\frac{3}{16}$	$4\frac{7}{16}$	$9\frac{3}{4}$	$6\frac{7}{8}$	$8\frac{13}{16}$	$6\frac{3}{16}$
31	$7\frac{3}{4}$	$5\frac{1}{2}$	7	$4\frac{15}{16}$	$7\frac{1}{8}$	$5\frac{1}{16}$	$6\frac{7}{16}$	$4\frac{9}{16}$	$10\frac{1}{16}$	$7\frac{1}{8}$	$9\frac{1}{16}$	$6\frac{7}{16}$
32	8	$5\frac{11}{16}$	$7\frac{1}{4}$	$5\frac{1}{16}$	$7\frac{3}{8}$	$5\frac{1}{4}$	$6\frac{5}{8}$	$4\frac{11}{16}$	$10\frac{3}{8}$	$7\frac{3}{8}$	$9\frac{3}{8}$	$6\frac{5}{8}$

it is desired to know the diameter of a single nozzle for a saturated-steam locomotive having a 20-inch cylinder and burning soft coal. This diameter, 20, multiplied by the factor .25 given at the top of the column, gives 5, which is the

nozzle diameter shown in the table. If a double nozzle was specified, the diameter of each of the nozzle openings would be $20 \times .177 = 3\frac{1}{2}$ inches. Where the table gives the diameter in sixteenths, the next smaller eighth is to be used.

DRAFT

48. Cause of Draft.—Draft in a locomotive is due to a difference in pressure on the gases in the firebox and in the smokebox. Draft is divided into two classes, *natural* and *forced*. With natural draft no apparatus or force is used to induce the flow of gases, other than the difference in the weight of the hot gases in the firebox and stack and the cooler air outside. The draft through a locomotive boiler when the engine is standing and the blower not working is natural draft. Forced draft, as the name implies, means that the draft is induced by other means. The flow of air through the grates, firebox, and tubes into the smokebox and out the stack when the locomotive is working is an example of forced draft.

FIG. 22

49. Action of Exhaust in Producing Draft.—The action of the exhaust steam in producing a draft is as follows: The steam after it has completed its work in the cylinders passes through the exhaust pipe and the stack to the atmosphere. The steam in passing through the smokebox carries some of the air with it by induced action, and this tends to cause a partial vacuum in the smokebox. The pressure of the atmosphere outside of the boiler forces fresh air into the ash-pan, through the fire and tubes, and into the smokebox to replace the air which was taken away by the exhaust steam, and thereby creates a draft. The rapidity with which the air and the hot gases change their relative positions depends upon the force of the exhaust steam; the greater the force of the exhaust the stronger will be the draft through the fire. The term partial vacuum as here used

means that the pressure of the gases in the smokebox after an exhaust is less than the pressure of the atmosphere, which is about 15 pounds to the square inch. The jet of exhaust steam should not fill the stack whether it is large or small until at a point very near the top as shown in Fig. 22.

THE BLOWER

50. Arrangement and Action.—The action of the exhaust steam in passing through the exhaust nozzle produces a draft through the fire only when the engine is working steam. The blower provides a means whereby a draft is produced

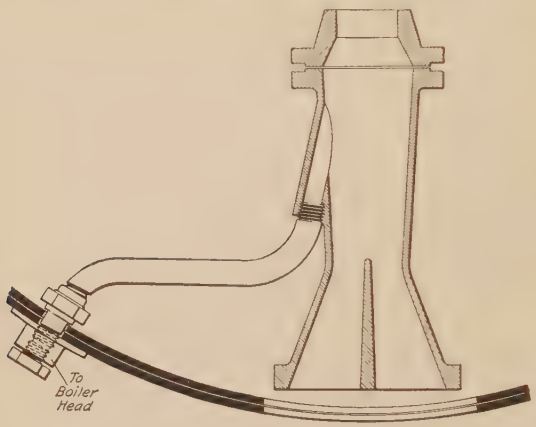


FIG. 23

when the engine is standing or running with steam shut off. The blower consists of a pipe which conveys steam from a valve on the back boiler head to the exhaust nozzle, or at a point near the base of the stack.

Figs. 23 and 24 show two different arrangements of the blower pipe at the smokebox. As shown in Fig. 23, the pipe from the boiler head connects outside the smokebox to a pipe that enters the exhaust pipe or the exhaust nozzle. A plug is provided at the junction of the pipes so that a steam hose can be connected and a draft created when the boiler is fired up in the roundhouse. The blower pipe may be connected

to the side of the exhaust pipe as shown in Fig. 23, or the pipe may be screwed into the exhaust nozzle as shown in Fig. 24, the

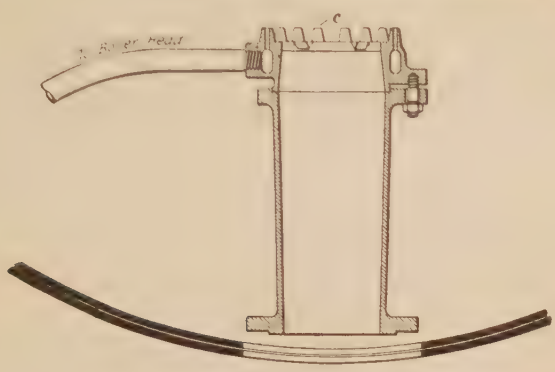


FIG. 24

outlet for the steam being through the small holes in the vertical projections *c*. The simplest arrangement for a blower is to bend a pipe in the smokebox until the end is n. the top of the nozzle and directly in line with the center of the stack. When the blower is in operation, a steady flow of steam passes through the blower pipe and the exhaust nozzle. The draft is created by the same action as that of the exhaust jet, that is, by the friction between the steam and the gases in the smokebox.

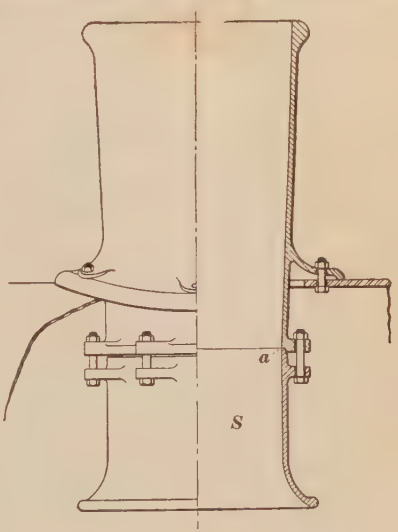


FIG. 25

THE SMOKESTACK

51. Description. The smokestack, or stack, is a cast-iron, sheet-iron, or pressed-steel pipe which is bolted to the top of the smokebox. Its purpose is to carry off the products of combustion from

the smokebox to a point above the engine and the train. Fig. 25 is a half outside and a half sectional view of a tapered stack of cast iron, which is used on boilers of large diameter. This stack is largest at the top and it then tapers 1 inch in 12 inches to *a* at the top of the extension *S*. The extension *S* extends down into the smokebox close to the nozzle and therefore no petticoat pipe is used.

An exterior view of a straight stack, which is made of sheet iron with a cast-iron base, is shown in Fig. 26. This style of stack is used on boilers of reasonably small diameter and is usually from 2 feet 6 inches to 3 feet high.

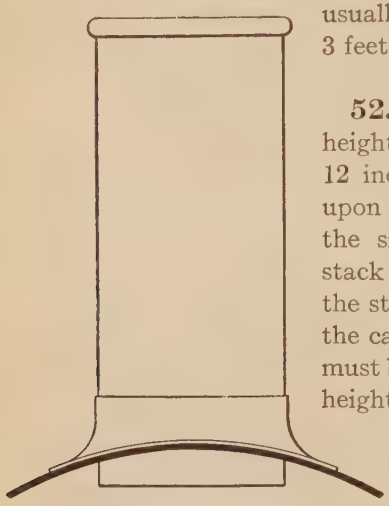


FIG. 26

52. Height of Stack.—The heights of smokestacks vary from 12 inches to 36 inches depending upon the size of the boiler. On the smaller sized boilers, a long stack can be used, and the longer the stack the better the draft. In the case of large boilers, the stack must be made much shorter and the height is usually determined by the clearance of the right of way. The top of the stack is therefore from 15 feet to 15 feet 6 inches above the rail. The stack should be of such a height that when the engine is running at moderate speeds one exhaust is entering at the bottom of the stack before the preceding one has escaped at the top. This action prevents a rush of cold air down the stack to fill the vacuum in the smokebox. With short outside stacks as in Fig. 25, the stack is not of sufficient height to prevent the entry of air, and the stack is accordingly lengthened by the extension *S* which is bolted to the base of the outside stack. How to determine the diameter of the stack will be explained in another Section.

SMOKEBOX DIMENSIONS

53. Earlier Arrangements.—The most satisfactory method of determining the dimensions of the smokebox, and the arrangement of the smokebox appliances is by experimenting with the various details until satisfactory results are obtained. The design of front end that was approved by the Master Mechanics' Association was the result of a long series of experiments in which the various details were thoroughly tried out. This arrangement however was intended only for

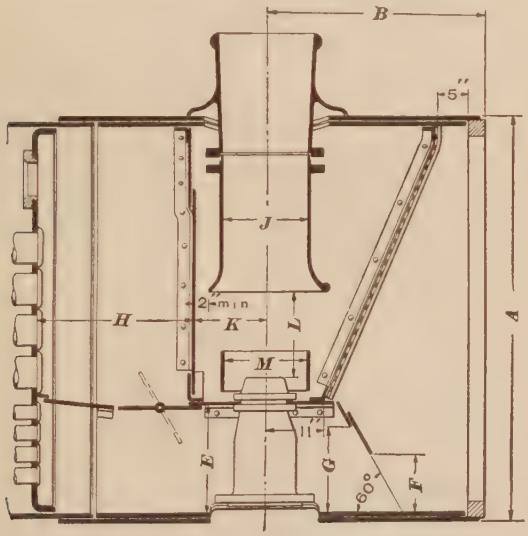


FIG. 27

coal-burning locomotives that used saturated steam, and therefore did not apply to superheated-steam locomotives. Also the arrangement was generally applicable to front ends of reasonably small diameter, or from 50 inches to 70 inches, while modern smokeboxes may have a diameter up to 105 inches.

54. Smokebox Standards.—The American Locomotive Company has adopted standards that cover the arrangement of smokebox details. The standard arrangement for different

sizes of smokeboxes can be obtained from Tables II, III, and IV, which give dimensions at the points indicated by the reference letters in Figs. 27 and 28. For example, *A* in Table II refers to dimension *A* in Figs. 27 and 28, or to the diameter of the smokebox; hence, all the numbers in the column under *A* in the table are smokebox diameters. By following this column through, it will be noted that the diameters given cover

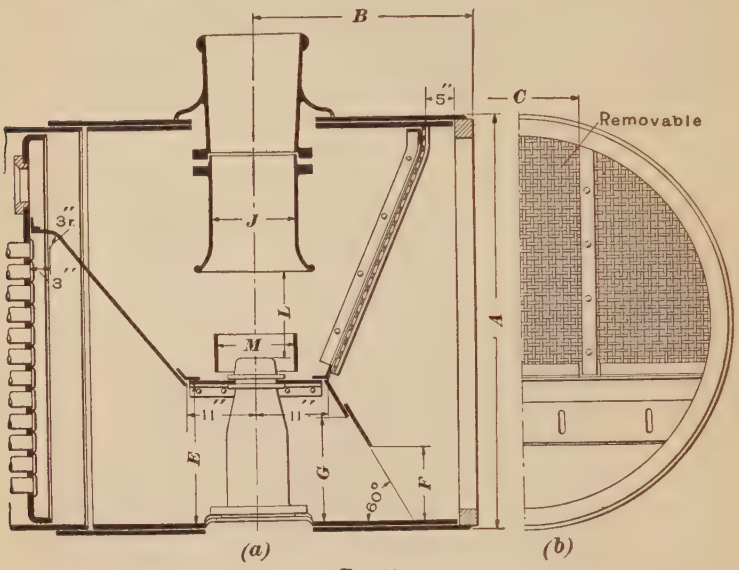


FIG. 28

a wide range, or from 50 inches to 105 inches. Other dimensions are likewise indicated by the letters *B*, *C*, *J*, *K*, etc.

55. Locating Position of Stack.—Table II shows how to determine dimension *B*, Figs. 27 and 28, or the distance in inches that the center of the stack should be placed from the front end of the smokebox for any diameter of smokebox from 50 inches to 105 inches. Dimension *B* is found as follows: Assume that the diameter of the smokebox, or *A*, Figs. 27 and 28, is 75 inches; next find the number 75 under *A* in Table II and note the number in column *B* which is opposite it. This is 39; then dimension *B* is 39 inches, or the center of the

stack should be 39 inches from the front of the smokebox when the diameter of the smokebox is 75 inches. Dimension *C*, or the width of the center piece of netting Fig. 28 (*b*) for the same diameter of smokebox, is found from Table II in the same way. The number opposite 75 in the column under *C* is 22

TABLE II

STANDARD SMOKEBOX DIMENSIONS

For significance of letters, see Figs. 27 and 28

A = Diameter of Smokebox

A Inches	*B* Inches	*C* Inches	*A* Inches	*B* Inches	*C* Inches	*A* Inches	*B* Inches	*C* Inches
50	31	14	69	37	20	88	43	27
51	31	14	70	37	21	89	44	27
52	31	15	71	38	21	90	44	27
53	32	15	72	38	21	91	44	28
54	32	15	73	38	22	92	45	28
55	32	16	74	39	22	93	45	28
56	33	16	75	39	22	94	45	29
57	33	16	76	39	23	95	46	29
58	33	17	77	40	23	96	46	29
59	34	17	78	40	23	97	46	30
60	34	17	79	40	24	98	47	30
61	34	17	80	41	24	99	47	30
62	35	18	81	41	24	100	47	31
63	35	18	82	41	25	101	48	31
64	35	19	83	42	25	102	48	31
65	36	19	84	42	25	103	48	32
66	36	19	85	42	26	104	49	32
67	36	20	86	43	26	105	49	32
68	37	20	87	43	26			

inches, which is therefore the width of the middle section of netting. Dimension *C* as determined by the table brings the two outer strips of netting about the same width as the center one, and also allows a proper width of door. The door is to extend the full height, as shown, for smokeboxes up to 90

inches in diameter. For diameters 90 inches and over, a door 30 inches high is used.

56. Position of Netting.—The netting is placed in accordance with the measurements given in Figs. 27 and 28 and reference does not have to be made to the tables to determine its position. As shown, the top of the netting is placed 5 inches from the front of the smokebox and 11 inches

TABLE III

DIMENSIONS FOR STANDARD CAST-IRON STACK EXTENSION

For significance of letters, see Figs. 27 and 28

J = Diameter of Stack Extension

J Inches	*K* Inches	*L* Inches	*M* Inches
11	11	13	9
12	12	13	10
13	12	14	11
14	13	14	12
15	13	15	13
16	14	15	14
17	14	16	15
18	15	16	16
19	15	17	17
20	16	17	18
21	16	18	
22	17	18	
23	17	19	
24	18	19	

from the center of the stack or exhaust pipe. With the netting located as shown, for any smokebox diameter given in Table II the clear area through the netting, or the gas area as it is usually called, will be one and one-quarter times the internal diameter of the tubes and flues. The term *clear area* means the total area of the openings in the netting. The foregoing statement holds true when the netting is designed in the first

place with a total clear area of 50 per cent., which means that the area of the openings is one-half the total area of the netting. However, if a netting is applied with a clear area of less than 50 per cent., the dimension given for *B* in Table II will not apply. In such an event the smokebox must be lengthened so as to permit the use of a netting that will give the minimum clear area allowable, or one and one-quarter times the gas area.

57. Dimensions K, L, and M. Dimensions *K*, *L*, and *M*, Fig. 27, can be obtained from Table III in where the diameter *J* of the cast-iron stack extension is known. Dimension *K* is the distance between the diaphragm and the center of the stack. Dimension *L* is the distance between the top of the nozzle and the base of the stack, and dimension *M* is the diameter of the short draft pipe which is placed around the exhaust nozzle. This pipe when used aids the draft to sweep the table plate clear of cinders. Let it be assumed that the stack has been measured and the diameter *J*, Figs. 27 and 28 (*a*), is found to be 18 inches. By reading Table III in the same way as has been explained for Table II, dimension *K* is found to be 15 inches, and dimension *L*, 16 inches. Dimension *K* is the minimum distance between the center of the stack and the diaphragm in a superheater locomotive, with a clearance of 2 inches between the diaphragm and the stack extension as shown. If necessary, the dimension *K* can be reduced by cutting 2 inches off the back of the extension casting.

58. Height of Table Plates.—Dimension *E*, or the height of the table plates, Figs. 27 and 28, is not determined from Tables II, III, or IV, but depends on the number of flues and tubes that are used. The height of the table plates must be such that the area beneath them is equal to the total internal area of the tubes and flues in the boiler. By the area beneath the plate is meant the area of a piece of plate which, if placed vertically, would fill completely the space between the smokebox and the table plate. The term *gas area* is usually applied to the total cross-sectional area of the tubes and flues. The foregoing applies when outside steam pipes are used, as

with superheater engines. With inside steam pipes, the dimension E, Fig. 28, is made 15 per cent. more than the total gas area. Under the conditions shown in Fig. 27 the table plates are not to be placed higher than the bottom row of superheater flues.

59. Height of Damper.—The maximum height of the damper is indicated by G, Figs. 27 and 28, and the minimum opening by F. These dimensions are not determined from the tables, but like dimension E, they depend on the total gas area. When the damper is at height G, the area under it should be 85 per cent. to 90 per cent. of the total gas area. When the damper is at height F, the area under it should be 63 per cent. to 68 per cent. of the total gas area. The damper may be moved between the limits F and G until the proper draft is produced. The damper should be set at an angle of 60 degrees in all cases.

60. Position of Diaphragm.—Dimension H, Fig. 27, or the distance between the front tube-sheet and the diaphragm, for a superheater engine, can be found from Table IV. In this table, the heading Number of Rows Deep of the second column refers to the number of flues when counted vertically. The heading Number of Rows Wide above the other columns refers to the rows of tubes when counted horizontally. Assume that, with the improved through-bolt type of header, the superheater flues are five rows deep and that they are from eight to nine rows wide. Opposite the number 5 in the column headed Number of Rows Deep, the number 33 is found in the column headed 8 to 9, hence the correct position of the diaphragm is 33 inches from the front tube-sheet. With the same number of flues deep and wide but with the **T**-bolt type of superheater header, the diaphragm is placed 21 inches from the tube-sheet. The height of the plate, as already explained, depends upon the gas area or the total internal area of the tubes and flues.

The position of the diaphragm with a saturated-steam engine is not given in the tables, but can be found in Fig. 28 (a). This figure shows that the bottom end of the diaphragm is placed

on the table plate 11 inches from the center of the stack. The upper end is secured to an angle iron directly below the steam pipe. The bend in the plate begins 3 inches from the tube-sheet, and is made with a radius of 3 inches.

61. Length of Smokebox.—When the diameter of the smokebox, the stack diameter, and the flue arrangement are

TABLE IV

DISTANCE BETWEEN FRONT TUBE-SHEET AND DIAPHRAGM, DIMENSION H, FIG. 27

Style of Header	Number of Rows Deep	*H*		
		Number of Rows Wide		
		5 to 7	8 to 9	10 to 12
		Inches	Inches	Inches
Improved Through-Bolt	2	19		
	3	24	25	
	4	28	29	30
	5	30	33	37
	6		37	38
Tee-Bolt	3	16	16	16
	4	18	18	18
	5	21	21	21
	6		24	24

given for a superheater locomotive, the length of the smokebox can be readily found from the tables. With a smokebox diameter of 80 inches, dimension *B*, Fig. 27, according to Table II, is 41 inches. If the stack diameter is 20 inches, dimension *K*, Table III, is 16 inches. If the superheater flues are 6 rows deep and 8 to 9 rows wide, dimension *H*, Table IV, is 37 inches. The total length of the smokebox is therefore $41+16+37=94$ inches, or 7 feet 10 inches.

THE FIREBOX

62. General Description.—A section taken lengthwise through a locomotive firebox is shown in Fig. 2 (*a*). The firebox is the furnace or box in which the fuel is burned, and the sheets which comprise it are surrounded by water on all sides. The heat of the fire is transmitted to the water through the sheets, hence there is an exceedingly rapid generation of steam around the firebox.

The firebox is made up of five sheets, the back tube-sheet, the crown sheet, the back, or door, sheet, and the two side sheets. A firebox with a combustion chamber as shown requires an inside throat sheet. The bottom of the firebox is formed by the grates.

The side, the door, and the crown sheet are usually made from $\frac{3}{8}$-inch plate, this thickness having been found to give the best results, and the tube-sheet is either $\frac{1}{2}$ or $\frac{5}{8}$ inch thick.

With the older types of locomotives having the firebox between the frames, the width of the firebox was about 3 feet and the length from 5 to 8 feet. The grate area varied between 15 and 24 square feet. With modern locomotives, the firebox is raised from between the frames and the width and length are increased until the width is now anywhere from 3 feet 6 inches to 10 feet and the length from 5 to 15 feet. The grate area varies from 20 to 110 square feet, depending upon the requirements of the locomotive.

63. The space between the inner and the outer sheets of a firebox is called the water leg. The water leg varies in width from 3 to 7 inches at the bottom and gradually increases in width toward the top. The greater width at the top allows for the free circulation of the steam bubbles as they rise to the surface of the water. The bottom of the water leg is formed by a cast-steel or wrought-iron ring *o* called the foundation ring, or mud ring, to which the outside sheets and the firebox sheets are riveted. The rivets pass through both sheets and the ring and are headed on both sides. From two to six arch tubes *b* are placed lengthwise in the firebox, the number used depending

on the width of the box. These tubes serve the double purpose of aiding the circulation of the water through the boiler and of supporting the firebrick arch b_1.

CONSTRUCTION OF FIREBOX

64. Firebox Sheets. — The several sheets of a firebox are joined together by means of a riveted joint, a single row of rivets of about $\frac{3}{4}$ inch in diameter being used. Fig. 29 shows a single-riveted lap joint such as is used in firebox construction. It is advisable, as far as possible when this style of joint is used, to keep the heads of the rivets away from the direct action of the fire. Otherwise the amount of the metal at one place is liable to cause overheating and the seam soon starts to leak. To overcome the disadvantage of having the rivet heads on the fire side, a style of rivet shown in Fig. 30 is used. This style is used on the flanges of the tube and the door sheets from the bottom of the sheet up to a height above that of the fire. It is evident that with such a method of riveting the action of the flames on the rivet heads is much less than with the type shown in Fig. 29, because the heads have very little more metal than the thickness of the plates.

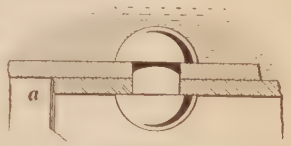


FIG. 29

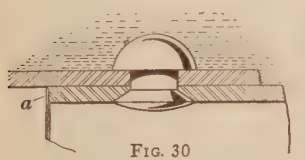


FIG. 30

65. On the fire side of the seam, Figs. 29 and 30, is shown a recess a which is made by calking the joints steam-tight. Where possible, especially in firebox work, it is an advantage to calk both the water and the fire sides, as this makes a much more efficient joint so far as leaking is concerned.

Instead of having the side sheets and crown sheet separate, plates are now made of sufficient size to make the entire side sheets and crown sheet in one piece. This is a great advantage, as it does away with the riveted joints between the two sheets and gives a more effective heating surface.

66. Door Hole.—The door hole in the back, or door, sheet is constructed in a number of different ways. Fig. 31

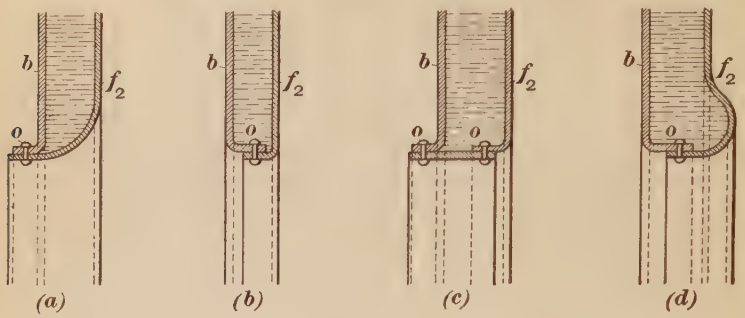


FIG. 31

shows four methods that are used to connect the back sheet f_2 to the back head b. The sheet f_2 surrounding the door opening is flanged, view (a), to a large radius and extends

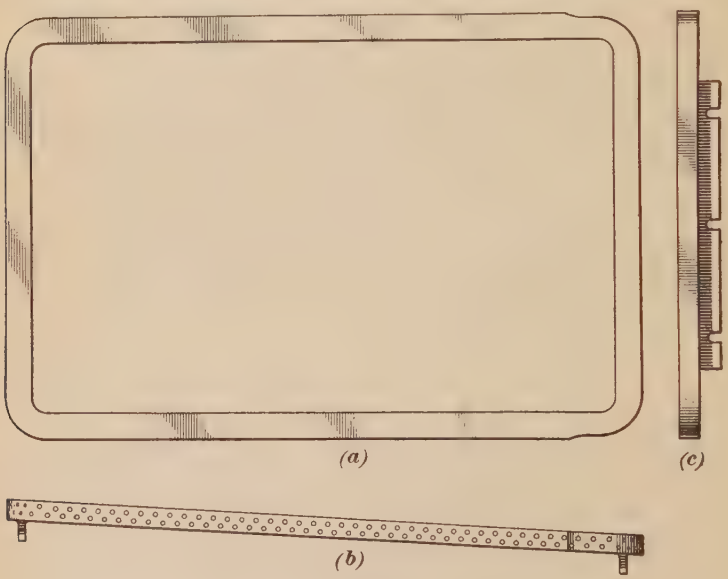


FIG. 32

through to the outer sheet b, the two sheets being riveted together at o. In view (b), the door sheet f_2 is shown flanged

outwards and the back head b is flanged inwards, and the two are riveted together at o. View (c) shows what is called the sleeve door, in which both sheets are flanged outwards, and a separate piece is rolled to the shape of the door hole and is welded and then riveted to the sheets at o. Owing to the continual expansion and contraction caused by the alternate heating and cooling of the inner sheet around the fire-door as the door is opened and closed, the sheet when flanged in a single curve as in views (a), (b), and (c) is liable to crack. A method of overcoming this is shown in view (d), where the door sheet f_2 is flanged to an ogee curve. This construction allows considerable movement without causing any rupture or distortion of the sheet.

67. The Foundation Ring.—The foundation ring, also called the firebox ring and the mud ring, is a casting or forging that separates the inside and outside firebox sheets at the bottom, and to which those sheets are riveted.

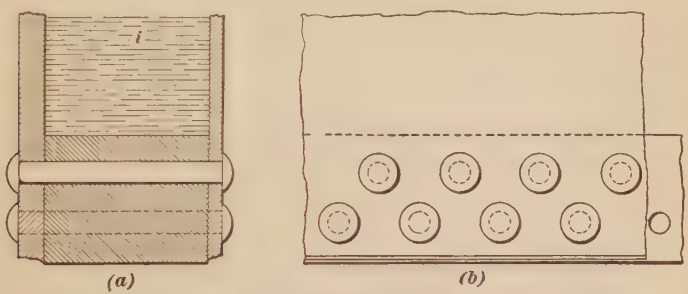


FIG. 33

Fig. 32 (a) shows the foundation ring as viewed from the top, and views (b) and (c) as seen from the side, and rear. Fig. 33 (a) is a section taken through the ring and the firebox sheets, and view (b) is an exterior view which shows how the outer sheet is riveted to the ring.

The ring, Fig. 32 (a), is rounded so as to eliminate the sharp corners. The two sheets, Fig. 33 (a), are secured to the ring by two rows of rivets which are headed on each side. View (b) shows the zigzag method of riveting which is always used when double riveting is resorted to. In some cases,

instead of full heads on the rivets on the fire side as shown in view (*a*), the sheet is countersunk and the rivets are driven in much the same manner as shown in Fig. 30.

Foundation rings are made from 3 inches to 7 inches wide and from $2\frac{1}{4}$ inches to $4\frac{1}{2}$ inches thick, depending on the width of the water legs and whether one or two rows of rivets are used.

68. Water Leg.—The water leg *i*, Fig. 33 (*a*), is the space between the outer and inner sheets of the firebox. It is a very important part of the water space of the boiler because, containing water, it prevents the firebox sheets from becoming overheated by the extreme heat of the fire. The water evaporates very rapidly in the water leg and this causes a continuous circulation of water around the firebox. On account of the head of water in the boiler, the pressure at the bottom of the water legs is slightly greater than that at the top. The pressure due to the head of water and the steam pressure tends to force the firebox sheets inwards and the outside sheets outwards, hence the necessity of very careful staying.

STAYING THE SIDE SHEETS

69. Staybolts and Crown Stays.—The sheets that comprise the firebox are stayed to the boiler shell which surrounds it by staybolts. The name *staybolts* is applied to the bolts used to stay the side sheets, the tube-sheet, and the door sheet to the boiler shell. The name *crown staybolts* or *crown stays* is applied to the bolts used to stay the crown sheet to the roof sheet.

70. Staybolts.—Staybolts are of two general classes, rigid and flexible. Rigid staybolts are applied so that each end is rigidly connected to the sheets, hence the name. A flexible staybolt is one in which one end is rigidly connected to one sheet while the opposite end is free to move in the other sheet, or both ends may be rigidly connected and the middle portion may be constructed so as to be flexible. Staybolts are necessary so that the firebox sheets will withstand the strains

due to the steam pressure, and to the expansion and contraction of the sheets. Staybolts constitute one of the most important details in boiler construction, the material, the design, and the method of application being all of equal importance. A true stay is one in which the bolt is at right angles to the sheets which it connects. Therefore it is necessary that all staybolts be at right angles to the sheets or as near so as possible.

Staybolts are manufactured from refined wrought iron to standard specifications, and are from $\frac{7}{8}$ to $1\frac{1}{8}$ inches in diameter. If of the rigid type, they may be threaded throughout their whole length or they may have their center portion turned down to a slightly smaller diameter.

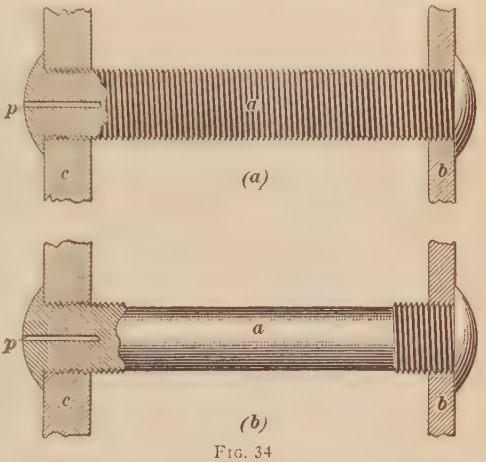


Fig. 34

71. Application of Rigid Staybolts.—Fig. 34 shows the application of rigid staybolts *a* to the side sheet *b* and the outside firebox sheet *c*. The method of application is as follows: After the sheets are bolted in place, the holes are tapped out with a long tap so that the threads of one sheet are in alinement with the threads of the other. The staybolts are then screwed into place and adjusted so that there is about $\frac{1}{4}$ inch of stock on the outside of both sheets to provide metal for heading over. Any surplus is cut off and the ends are riveted over as shown. The standard thread used on staybolts is twelve threads to the inch. Staybolts frequently break, and to enable warning to be given when this happens, a tell-tale hole *p*, $\frac{3}{16}$ inch in diameter, is drilled $1\frac{1}{4}$ inches deep in the outer end of the bolt. As the bolts invariably break at the outer ends steam escaping from the hole will

give warning. The tell-tale hole must always be kept open.

Hollow staybolts are sometimes applied, this type having holes entirely through them. The holes serve the purpose of supplying air direct to the firebox above the fire, two rows being placed above the fire line.

72. Movement of Firebox Sheets.—There is a more or less continuous movement of the firebox sheets and therefore of the staybolts, due to the alternate high and low temperatures of the firebox, which cause the sheets to expand and contract. The variations in temperature are the greatest when

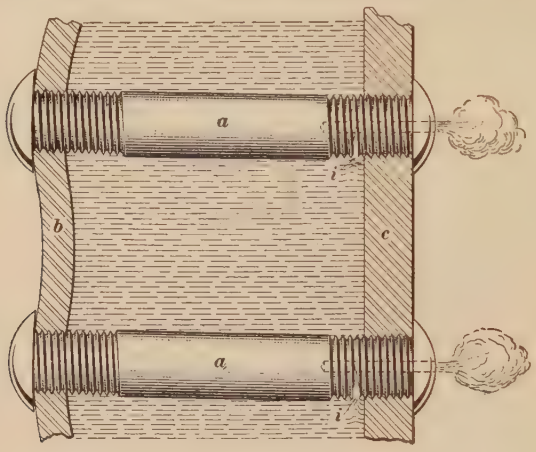


FIG. 35

firing up a cold engine. The movement of the sheets is more pronounced at the top and the ends of the firebox, because the sheets are rigidly connected at the bottom to the foundation, or mud, ring and any movement must be upwards and lengthwise. As the temperature of the inner sheet is greatly in excess of that of the outside sheet, the expansion and contraction of the inner sheet is the greater. This greater movement of the inner sheet causes stresses to be set up in the staybolts, which will eventually break them, the fracture in most cases occurring at the outer sheet. The effect of the movement of the firebox sheet is shown in Fig. 35. This figure shows a section through a part of the firebox sheet, *a*

being the staybolts, b the firebox sheet, and c the outside firebox sheet. The application of heat to the firebox sheet b causes it to expand much more rapidly than the outer sheet c, which is comparatively cool. This movement distorts the inner sheet b, as shown, and causes the sheet and the staybolts to assume new positions in relation to the outer sheet. On becoming cool, the sheet tends to resume its original position. This continual movement soon causes a fracture in the staybolt, as shown at i, and the bolt will not carry the load for which it was designed.

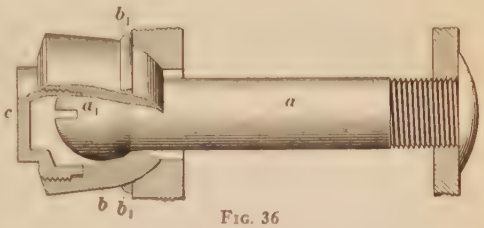


FIG. 36

73. Application of Flexible Staybolts.—A flexible staybolt is one that is designed to allow for the difference in the expansion and contraction of the inner and the outer firebox sheets without placing undue strains on the sheets or the bolt. This type of staybolt is now in general use. The flexible staybolt shown in Fig. 36 consists of a bolt a having a spherical-shaped head a_1 which fits snugly in a sleeve b. The sleeve is welded to the outside firebox sheet, the metal forming the weld being shown at b_1. A cap c which makes a tight joint is screwed into the outer end of the sleeve. The method of application is as follows: A hole is drilled in the outer sheet and the sleeve is welded in place. The staybolt tap is then run through the sleeve and the hole in the firebox sheet is tapped out. The bolt is screwed into place, the surplus cut off, the bolt headed over on the fire side, and the cap nut applied. The earlier types of flexible staybolts had the sleeve screwed into the sheet instead of welded to it. This type of staybolt is illustrated in Fig. 37.

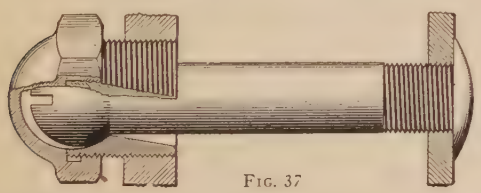


FIG. 37

Staybolts of either of these kinds allow the firebox sheet to move more or less without causing undue stress on the sheet

Fig. 38

or the outer end of the bolt. Incrustation or the accumulation of mud, etc., around the head of the bolt, in the sleeve, will produce the effect of a solid bolt; therefore a mixture of graphite and oil is applied around the bolt head when the cap is removed.

74. The flexible staybolt shown in Fig. 38 differs from that shown in Figs. 36 and 37. The reason for the flexibility possessed by this type of staybolt can be more readily understood if the process of manufacture is considered. This is illustrated in Fig. 39. The bolt is first slotted as shown in view (*a*), the sharp edges are rounded and the surface of the slot smoothed as in (*b*), then the body section is reduced by rolling to the form shown in (*c*). The bolt is then twisted one-third of a turn, threaded and squared, and the tell-tale hole is drilled in it. The middle portion of the bolt may be

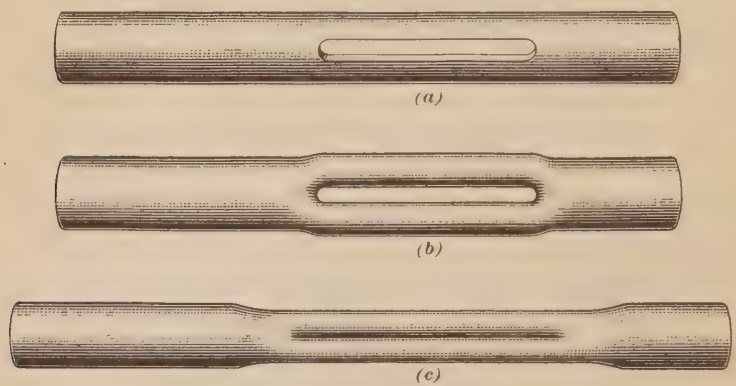


Fig. 39

compared to a rope with two strands loosely twisted. When the bolt is subjected to a twisting strain the middle portion

of the bolt will give and allow the sheet to move without distortion and without subjecting the staybolts to severe strains. This action is illustrated in Fig. 40, which shows a portion of the firebox sheets connected by staybolts of this type. As the sheet *b* moves, the central portions of the bolts open or close, depending on the direction of the movement of the sheets, and the flexibility of the bolts prevents the strains on their ends such as occur when the staybolts are rigid.

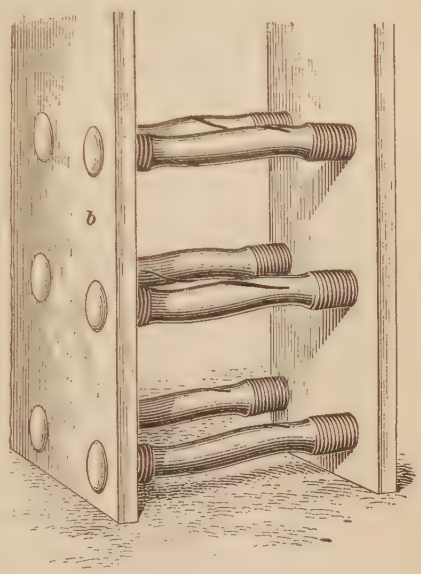


FIG. 40

75. In some cases, the entire installation is of flexible staybolts, while in other cases they are installed only in what is known as the breaking zone which is that part of the firebox where the tendency for breakage is greatest. The breaking zone usually comprises two or three upper rows along the sides, the first six or eight rows toward the ends, and the outer rows on the back head and throat sheet.

STAYING THE CROWN SHEET

76. Crown Staybolts and Crown Bars.—The crown sheet is the sheet or plate which forms the top, or the roof, of the firebox. The crown sheet may be made separate from the side sheets, or the sheets may be made in one piece. The crown sheet is supported from the roof sheet by crown or radial staybolts, or by the crown-bar method. In modern practice, staying by crown bars has been almost entirely superseded by the staybolt method.

77. Crown Staybolt.—A crown staybolt, or crown stay, is a staybolt that is used to connect the crown sheet with the roof sheet. It serves the same purpose for the crown sheet as the staybolts do for the side sheets. As with the firebox staybolts, the crown staybolts may be either rigid or flexible. To be most effective, the staybolts should be as nearly as possible at right angles to the surfaces they support. This is not possible in modern locomotive-boiler construction, because the roof sheet is usually of large radius, and the crown sheet is more or less flat or of small radius. Therefore, when the crown stays are placed as nearly as possible at right angles to the crown sheet their arrangement will resemble the spokes of a wheel or will be radial, and they are generally referred to as *radial stays*.

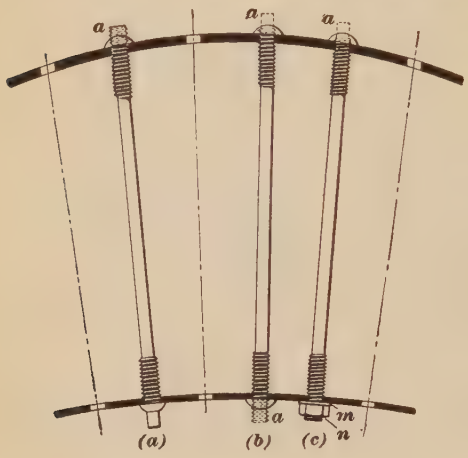


FIG. 41

78. Rigid Crown Stays.—Fig. 41 shows three different types of rigid crown staybolts all of which are applied in a different manner. View (*a*) shows a *button-head crown bolt*, so called because of the shape of the lower end. This type of bolt is applied from the firebox side, the staybolt being screwed up snugly against the under side of the crown sheet and through the roof sheet, and the outer end riveted over. The square projection on the firebox end of the bolt permits of its being screwed into place. View (*b*) shows a stay that is screwed through both sheets and both ends riveted over. View (*c*) shows a stay that is applied through the roof sheet. The stay is then riveted over on the outer end and a copper washer *m* and a nut *n* are applied to the firebox end of the bolt. The parts *a* on the ends of the bolts, views (*a*), (*b*)

and (*c*), show the ends before they are riveted over. Screw crown stays usually have the middle portion of the bolt turned down slightly smaller in diameter than the threaded portion, as this aids in the application of the bolt. All staybolts and crown stays should be placed 4 inches to 4½ inches apart each way in the firebox sheets. In the outer sheet this distance may be increased or decreased according to the curvature of the sheet.

79. With the style of stay that is riveted over at both ends as in view (*b*), a square end *a* is forged on the outer end of the bolt. This square end in addition to being used when threading the bolt is also used when applying the bolt to the boiler. To apply the bolt, the square end is placed in a pneumatic tool and run into place, or a wrench may be applied to this end. When the stay is in position, the squared end, together with such other surplus as there may be, is cut off, only enough material being left to make a good head.

In all cases where the crown stays have button heads with squared ends next to the crown sheet as in view (*a*), it is advisable to cut off the square ends before the boiler is put in service. This prevents overheating of the bolt heads, on account of the amount of metal at this point and consequent leakage. The most satisfactory way of cutting off the ends is to fill the boiler with water until the crown sheet is covered and then cut off the square ends below the button heads with an oxyacetylene torch. The boiler is filled with water so as to prevent the heat of the torch from starting the joint between the bolt and the sheet. In the process of machining a button-head crown bolt, view (*a*), the part of the head that comes against the sheet is slightly undercut or dished out. When the head is tightened against the sheet, the outer edge of the head comes in contact with the sheet first, and as the bolt is tightened the head makes a steam-tight joint with the sheet.

80. Flexible Crown Stays.—Flexible crown stays prevent the expansion and contraction of the crown sheet from setting up undue strains in the sheet or the staybolt.

Fig. 42 shows two types of crown stays which are applied in a different manner.

The type of stay shown in view (*a*) is screwed up tight through the crown sheet, the nut *a* is applied to the opposite end and brought to its bearing in the sleeve a_1, which has been previously welded to the roof sheet. The cap nut a_2 is then screwed into the sleeve.

A stay of the type shown in view (*b*) is applied as follows: The roof sheet and crown sheet are punched or drilled as usual and the hole in the roof sheet is reamed and tapped for

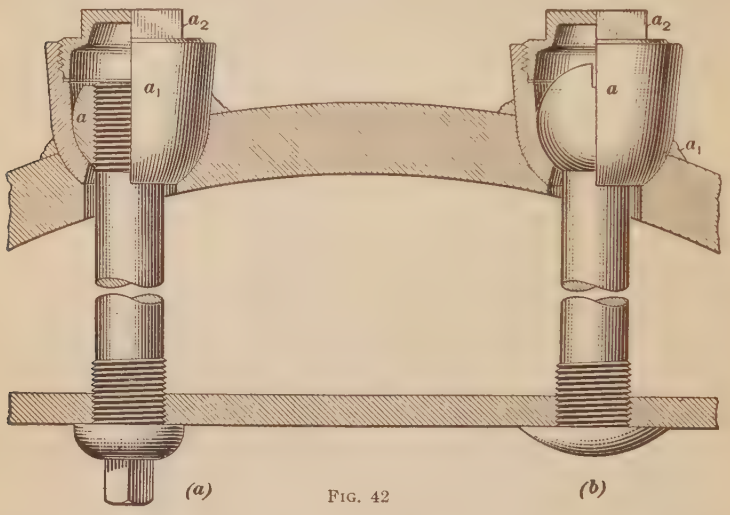


FIG. 42

the sleeve *a*, which is electrically welded to the sheet, the welding metal being shown at a_1. After the sleeve is welded, the tap is run through the sleeve into the crown sheet and the hole is tapped out. The bolt is inserted through the sleeve and the lower end is screwed through the crown sheet. A riveting plug is then applied to the outer end of the bolt, the inner end is riveted over, and the cap a_2 is applied.

81. Fig. 43 shows how a portion of the roof sheet appears when flexible crown stays of the types described are used. In the illustration, the cap nuts have not yet been put in place.

As with the flexible staybolts, the earlier types of flexible crown stays had the sleeves screwed into the sheet instead of welded to it. The sleeves when welded are less liable to leak than when threaded. The staying of the crown sheet by crown stays in addition to being more efficient than the crown-bar method has the advantage of making the crown sheet practically self cleaning. On account of the curve of the sheet, any impurities that settle on it are washed off by the circulation of the water.

82. Crown-Bar Method.—With the steam dome placed over the crown sheet, as was the general practice with the

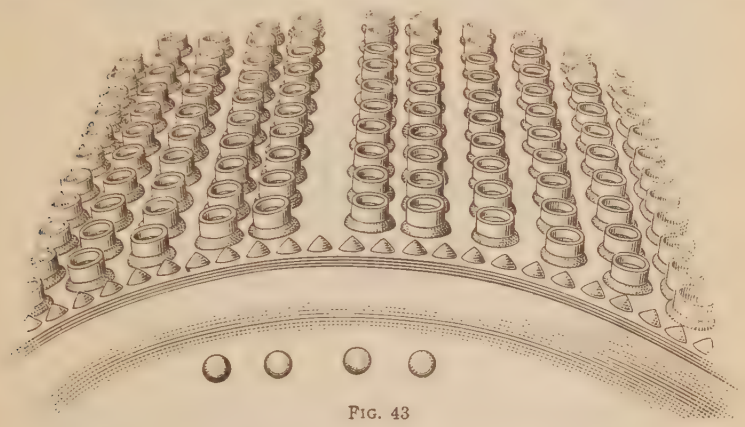


FIG. 43

older types of boilers, it was necessary to use the crown-bar method of supporting the crown sheet. The reason was that the opening made in the roof sheet by the dome prevented the section of the crown sheet beneath it from being supported by crown staybolts. However in some cases that part of the crown sheet not under the dome was supported by crown staybolts instead of crown bars.

In Fig. 44 the cylindrical part of the boiler in front of the tube-sheet is removed so that the crown bar over that part of the crown sheet next to the tube-sheet may be seen. Fig. 45 is an enlarged view of a portion of the arrangement shown in Fig. 44.

83. The crown bar a, Fig. 44, as shown in Fig. 45 (b), is generally made of two pieces of plate spaced about $1\frac{1}{4}$ inches apart, except at the ends, which are welded together. The ends of the bars may be connected by pins a_1 to the brackets a_2 on the roof sheet, as shown in Fig. 44, or the ends may have feet that rest upon the crown sheet, where it is riveted to the side sheets. The crown bolts a_3, Fig. 45 (a) and (b), are screwed through holes punched and tapped in the crown sheet, and pass up through the thimbles a_4 and between the two sections of the crown bar. Washers a_5, the ends of which fit over the sides of the crown bar, are placed on the bolts, and the nuts a_6 are then applied and drawn up tight. The thimbles a_4 serve to keep the proper space between the crown sheet and

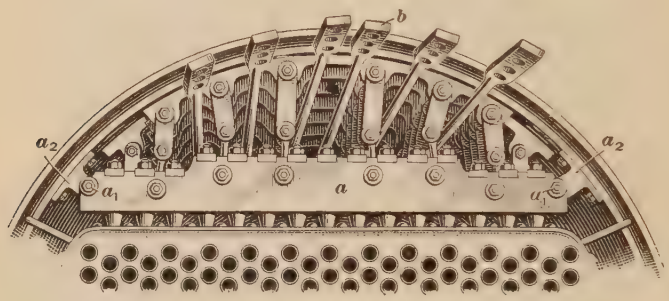


FIG. 44

the crown bar. The crown bars are connected to the brackets, or T irons a_7, on the roof sheet by the crown-bar links a_8 and slings a_9. The lower ends of the links are connected to the crown bars by the pins a_{10}, and the upper ends of the slings are fastened to the bracket by the pins a_{11}. The links and the slings are pinned together as shown. The braces b, Fig. 44, are used to brace the back head to the roof sheet. In some installations the lower ends of the slings are pinned directly to the crown bars. The threads on the crown bolts, Fig. 45, are cut so as to make a steam-tight joint, and the bearing of the button on the head of the bolt against the plate is also designed to prevent a leak even if the threads fail to do so.

84. The objections to the crown-bar method of staying are as follows: The crown bars take up considerable water

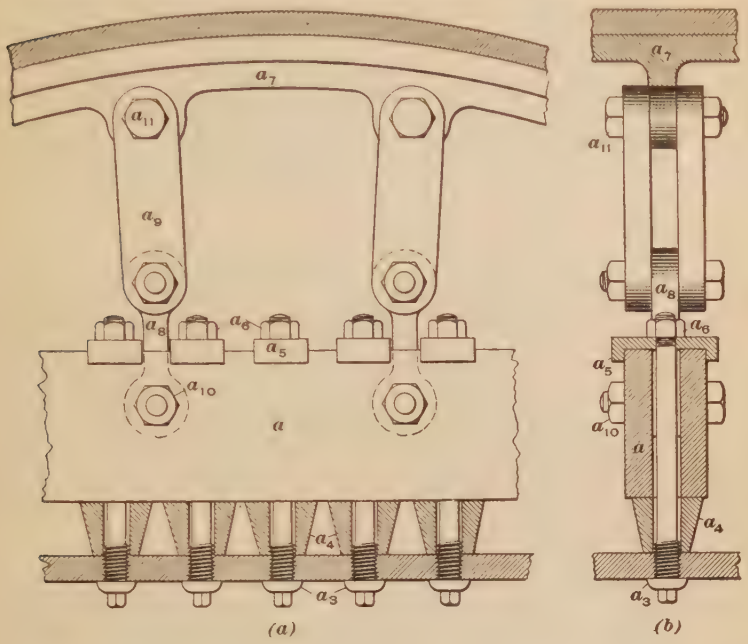


FIG. 45

space, are heavy, and they make it very difficult to keep the top of the crown sheet clean. Also they are not adapted to other than flat sheets.

85. Staying Sheets on Oil-Burning Locomotives.—On oil-burning locomotives, the staying of the crown sheet requires particular attention on account of the liability of the heads of the staybolts to be burned off by the intense heat of the fire. To overcome this, and also to have an added security, the bolts are enlarged at the fire end, as shown in Fig. 46, and threaded on a taper so that in case of an overheated sheet, the sheet will not pull away from the bolt so readily as in the case of a straight threaded bolt.

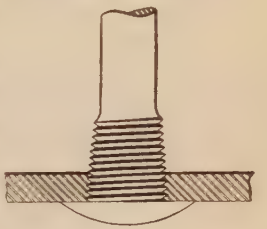


FIG. 46

86. Importance of Staybolts.—That staybolts and crown bolts are a very important detail in boiler construction is emphasized by the Federal law which read as follows: "No boiler shall be allowed to remain in service when there are two adjacent stays or crown bolts broken or plugged in any part of the firebox or combustion chamber, nor when three or more are broken or plugged in a circle 4 feet in diameter, nor when five or more are broken or plugged in the entire boiler."

LOCOMOTIVE BOILERS

(PART 2)

CONSTRUCTION, DETAILS, AND MAINTENANCE—(Continued)

FIREBOX APPLIANCES

PURPOSE

1. The purpose of the different appliances that are installed in the fireboxes of modern locomotive boilers is to secure either a more complete burning of the fuel, or a more rapid circulation of water around the firebox and thereby a quicker generation of steam. These appliances comprise firebrick arches, combustion chambers, arch tubes, and thermic siphons.

ARCH TUBES

2. An arch tube is an iron or steel tube, 3 inches to $3\frac{1}{2}$ inches in diameter, that is used to promote the circulation of the water around the firebox and to support the brick arch.

The position of the arch tubes in the firebox is shown at h in Fig. 1. In this figure, the back head of the boiler, the roof sheet, and the outside firebox sheets are omitted, the sheets shown being the firebox sheets. One end of the tube h is inserted in the door sheet f_2, and the other end, when a combustion chamber is used, is connected to the inside, or firebox, throat sheet. When a combustion chamber is not used,

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the front ends of the arch tubes are inserted in the tube-sheet below the tubes.

Arch tubes promote the circulation of the water, because the front ends of the tubes are in such a position that they receive the water from a point at the bottom of the boiler shell where it is comparatively cool. The water in the arch tubes evaporates very rapidly and is replaced by the cooler water which enters the tubes at their front ends, the result

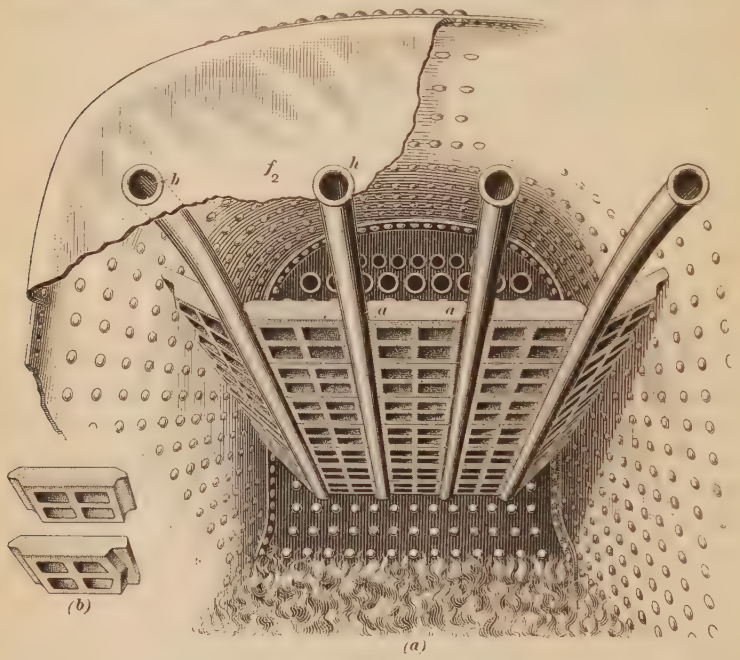

FIG. 1

being a strong flow of water, as indicated by the arrows in Fig. 2. The rapid flow of the water tends to make the other heating surfaces more effective. The number of arch tubes which are used varies from two to six, depending on the width of the firebox, and they are so placed that the firebrick will fit snugly on the top of them.

3. Application.—The method of applying the arch tubes to the firebox sheets is shown in Fig. 2, in which f_2

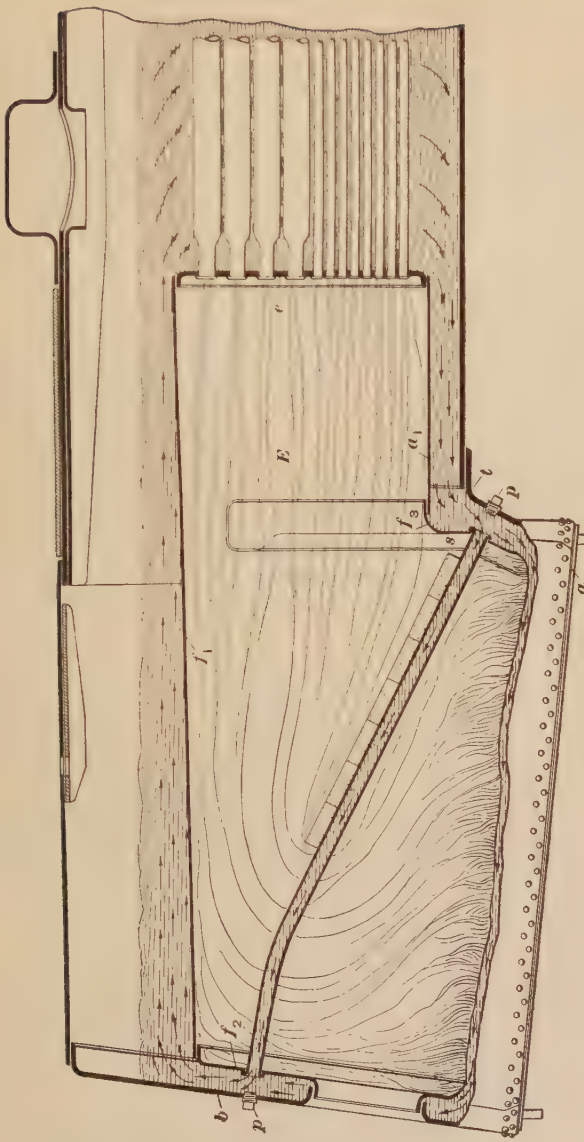

FIG. 2

indicates the door sheet, f_3 the inside throat sheet, b the back head, and t the throat sheet. The holes in the firebox sheets are drilled $\frac{1}{32}$ inch larger in diameter than the arch tube, so that it can be easily applied in place. The tubes are then bent to the required shape and cut to length. From $\frac{3}{8}$ to $\frac{1}{2}$ inch of the tube is allowed to project into the water space so as to provide material for beading over as shown in Fig. 3, which is an enlarged view of the back end of an arch tube, and an arch-tube plug.

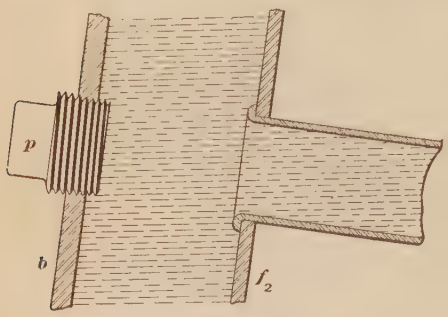

FIG. 3

Arch-tube plugs p, Fig. 2, are inserted in the back head b and throat sheet t so as to provide a means whereby the tubes can be rolled and beaded and also to give access for cleaning. The plugs are of standard taper $\frac{3}{4}$ inch in 12 inches and twelve threads per inch.

FIREBRICK ARCH

4. Description.—As the name indicates, the firebrick arch consists of an arch of firebrick built up in sections and set in the firebox in an inclined position. With a narrow firebox when arch tubes are not used, the arch is held in place by means of studs welded to or screwed into the side sheets. In wide fireboxes, the arch is held in position by the arch tubes.

Fig. 4 shows a cross-sectional view of a brick arch in a narrow firebox in which arch tubes are not used. In width, the arch consists of a series of two bricks a, a_1, the outer ends of which rest on studs a_2, the other ends being notched and recessed where they meet. The screw studs a_2 are screwed into the side

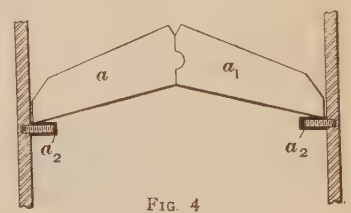

FIG. 4

sheets and are provided with sleeves which protect the stud from the fire. The sleeves are renewed as soon as they become burnt through.

When the arch is placed upon studs, its front end is located from 1 inch to 10 inches below the tubes, depending on the depth of the firebox, and extends back to a point at or slightly above the level of the fire-door.

5. In Fig. 1 (*a*) is shown a firebrick arch installed in a wide firebox, as seen from the firebox door. The sides of the bricks at *a* are shaped to fit the point where they rest on the arch tubes *h*. Next to the side sheets, the bricks rest against the sheets. The surface of the bricks exposed to the fire are dished out as shown. This construction retards the passage of the gases along the arch and also causes them to mix more completely with the air. An opening is left at the back end of the arch below the crown sheet to allow the gases to pass to the tubes. View (*b*) shows two of the firebricks removed from the arch. The lower brick is one that is placed along the side of the firebox, and the upper one shown is a middle brick.

The position of the brick arch divides the firebox into two sections, one below the arch, in which the fuel is consumed, and the other above the arch, which acts as a combustion chamber in case no other one is provided, and as an extension of the combustion chamber when there is one.

6. Position of Arch at Tube-Sheet.—The ideal method of setting brick arches is to place them tight against the tube-sheet. In this position, the tubes and flues receive the most protection from the currents of cold air that may enter through the grates at the front end of the firebox. In practice, however, it has been found advisable in many cases to leave spaces between the brick arch and the tube-sheet, as shown at *s*, Fig. 2. These spaces are formed by bricks so shaped as to provide the required opening, and yet hold the arch the proper distance from the sheet. This arrangement is necessary because fine coal and cinders accumulate on the top of the brick arch, more especially against the tube-sheet, and result in the lower rows of tubes becoming plugged. The coal and

cinders, when a space is left between the arch and the sheet, drop down through the opening into the fire below. The space also allows a draft and overcomes to a large extent the tendency, due to carelessness, to allow the fire against the tube-sheet to become dead. Spaces at the tube-sheet are especially desirable where the distance between the bottom of the arch and the grate line is comparatively short.

7. Advantages of Firebrick Arch.—The advantages of the firebrick arch are: (1) It lengthens the path of the hot gases to the tubes, thereby keeping them longer in the firebox and giving them more time to mix with the air and to burn; (2) it tends to maintain a more even temperature in the firebox and helps to prevent the gases from being cooled below their igniting temperature; (3) it prevents the direct action of the flames on the tube-sheet, thereby preventing burning off of the beads, and it also keeps the cold air from striking the tube-sheet and causing it to leak; (4) it prevents to a great extent the exhaust from pulling fine coal and unburned cinders through the tubes and tearing holes in the fire.

COMBUSTION CHAMBER

8. Description.—The combustion chamber *E*, Fig. 2, is a compartment or space in a locomotive boiler, between the firebox and the back tube-sheet, and is really an extension of the firebox forward of the grates; it may vary in length from 6 inches to 6 or 7 feet, depending on the size and capacity of the boiler.

In Fig. 5, the roof sheet *a* and the shell sheet *b* are broken away so as to show the exterior or water side of the combustion chamber *E*.

The type of combustion chamber shown in Figs. 2 and 5 is known, on account of its appearance, as the barrel, or built-in, combustion chamber. When the tube-sheet is directly in front of the grates, the space above the brick arch is sometimes referred to as the combustion chamber. A built-in combustion chamber is so constructed that the crown sheet f_1, Fig. 2,

forms the top, or the crown sheet, of the chamber although the sheet may be made in two separate pieces. An extra sheet f_3, Figs. 2 and 5, known as the inside or firebox throat sheet, must be used at the throat of the boiler to connect the foundation ring a with the sheet a_1 of the chamber. The use of combustion chambers requires a large number of additional staybolts and therefore more attention to them. The installa-

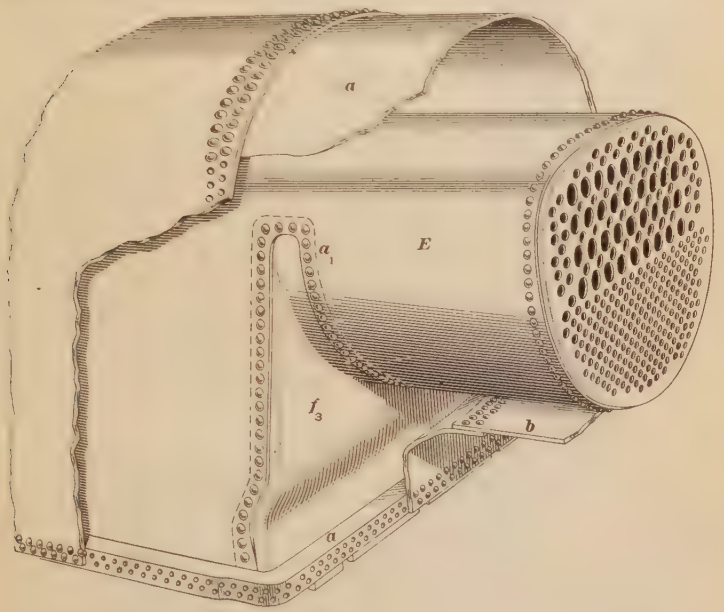

Fig. 5

tion of flexible staybolts properly applied will prevent much of the staybolt trouble in combustion chambers.

9. Advantages.—The surface of the firebox evaporates about five times as much water per square foot as does the surface of the tubes. Therefore, the advantage of the combustion chamber is that it gives more firebox heating surface and a greater evaporation with a specified grate area. The use of a combustion chamber in large boilers also permits the use of shorter tubes. Tubes of an excessive length cause the draft to lag at their front ends. With a combustion chamber the gases

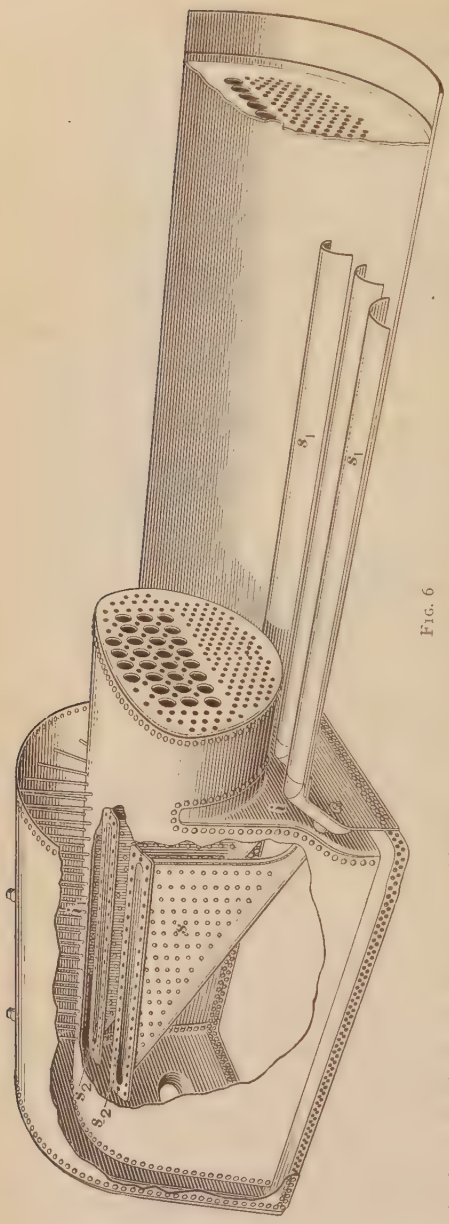

Fig. 6

have to travel farther before they enter the tubes and they therefore have a better chance of being thoroughly burned than if a combustion chamber is not used.

THERMIC SIPHONS

10. Description. The Nicholson thermic siphon is a device designed to increase the heating surface of the firebox and to aid the circulation of the water in the boiler.

Fig. 6 is a view of a boiler with the outer sheets removed so as to show the general arrangement of a siphon s and the intake channels s_1. Fig. 7 shows two siphons installed in a firebox, and Fig. 8 is a view of a siphon removed from the firebox. The rear ends of the intake channels s_1, Fig. 6, terminate near the necks of the siphons s, but these parts are not connected. The intake channels conduct the water in the front end of the boiler to the siphons.

11. Application.—The siphon s, Fig. 6, is a hollow triangular-shaped device and is so placed in the firebox that it connects the water space i in the front of the firebox with the water space i_1 above the crown sheet. Accordingly, an opening is cut in the crown sheet to correspond with the opening s_2 in the siphon, Fig. 8, and a hole is also cut in the tube-sheet for the siphon neck s_3. The upper flange s_4 of the siphon is butt-welded to the crown

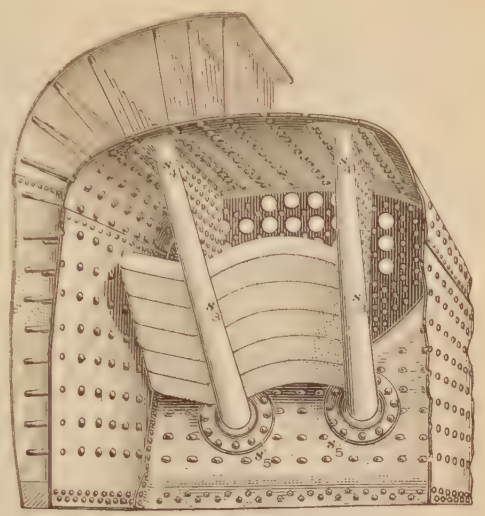

FIG. 7

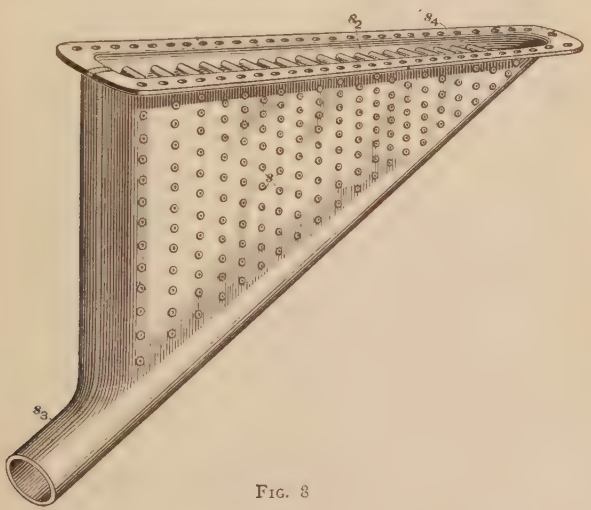

FIG. 8

sheet and the crown stays are inserted through the holes in the flange. The siphon neck is inserted into a flexible

diaphragm plate s_5, Fig. 7, which is riveted or welded to the tube-sheet. As shown in Fig. 9, the neck projects sufficiently to allow for beading over, and it is then welded to the flange of the diaphragm plate. A pressed-steel plate s_6 is riveted on the inside of the throat sheet s_7 in order to reinforce the unstayed surface of the throat sheet opposite the neck of the siphon. A wash-out plug is shown at s_9.

The siphon, Fig. 8, is made from a single piece of $\frac{3}{8}$-inch firebox steel cut to the required shape. The sides are $3\frac{1}{4}$ inches apart and are supported by the staybolts s, each of which has a tell-tale hole drilled into each end.

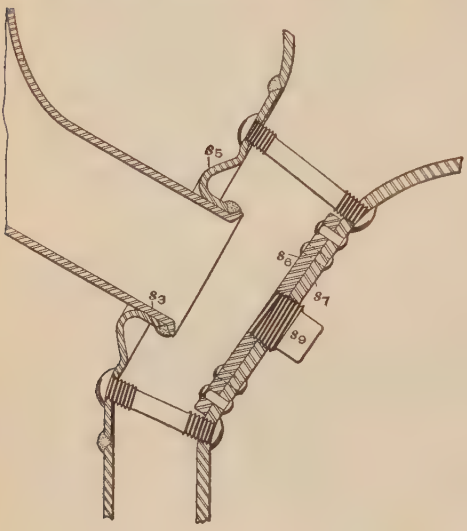

FIG. 9

As shown in Fig. 7, the circular portion of the siphon forms an excellent support for the firebrick arch. The number of siphons applied depends on the width of the firebox. There may be one, two, or three.

12. Operation and Advantages. The water in the siphon s, Fig. 6, as it evaporates is replaced by way of the intake channels s_1 by the cooler water in the front end of the boiler. The water after leaving the siphon s passes up over the crown sheet and forwards to the front tube-sheet again. The result is a quicker circulation of water and therefore a more rapid generation of steam.

Siphons increase the firebox heating surface because of the added surface that is directly in contact with the hot gases, this being equivalent to so much added crown-sheet area.

SPECIAL DESIGNS OF FIREBOXES

GAINES LOCOMOTIVE FURNACE

13. Description.—For locomotives of large capacity, a type of firebox has been designed known as the Gaines locomotive furnace which gives a firebox heating surface equal to that obtained by the use of the barrel type of combustion chamber shown in Fig. 2, and yet is of much simpler construction.

This type of furnace is shown in Fig. 10. The firebox is partitioned off by means of a firebrick arch or wall *a*, which is set in such a position that the required grate area is secured between the wall and the rear of the firebox. The part *E* of the firebox in front of the wall is utilized as a combustion chamber.

14. Advantages.—A firebox of the Gaines type gives the same amount of heating surface as that shown in Fig. 2, and has the advantage of being much easier and cheaper to construct and install. It does away with the large number of staybolts that are necessary with the barrel type of combustion chamber and requires less care and maintenance, especially in bad-water districts, because there are less water spaces where mud can accumulate. This type of furnace has another advantage in that the barrel of the boiler can be made slightly smaller than with the barrel combustion-chamber type without sacrificing any flue heating surface.

In some cases, however, due to the peculiar arrangements of some individual class of engines, which limit certain boiler dimensions, it is necessary to use a short combustion chamber which extends into the shell even with a furnace of this type.

15. Construction.—The firebrick arch or wall *a* is made up of bricks which rest on a cast-iron or steel cross carrier *b*, secured to the foundation ring on each side. The wall is 10 to 12 inches thick and is of a height to give sufficient space over the grates to burn the fuel properly. In the center of the wall are placed several, depending on the width of the firebox, heavy wrought-iron pipes *c* about 3 inches in diameter, which have caps *d* on the top. These cap

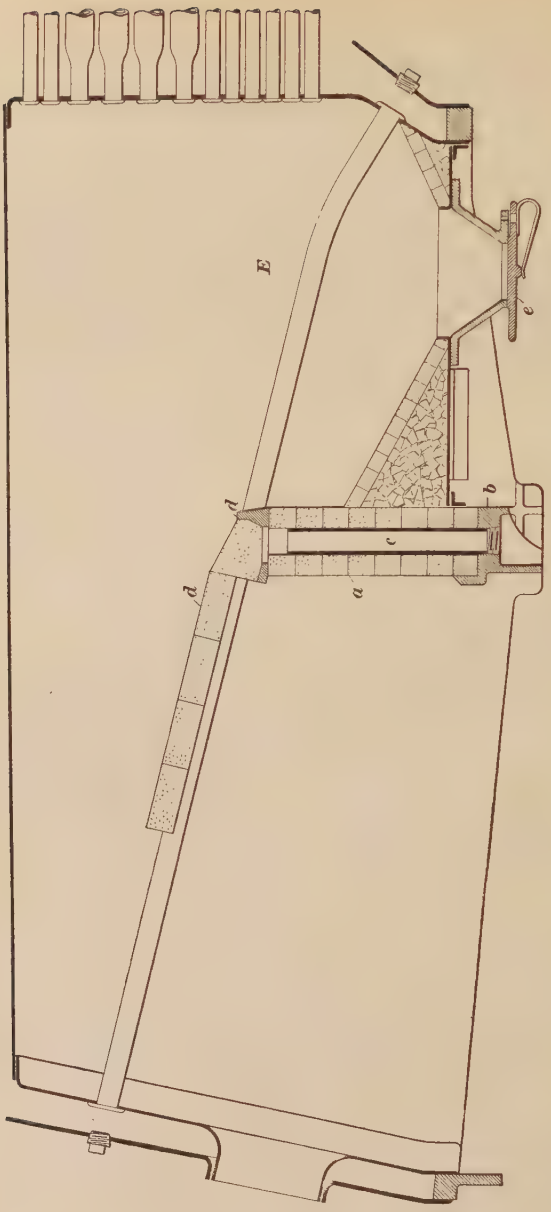

FIG. 10

castings act to hold the arch tubes securely and also as a brace for the arch *d* to prevent it from sliding forwards on the tubes.

After the wall has been placed and the tubes rolled and set in position, the caps *d* are wedged under the arch tubes, thereby holding all parts of the wall and arch securely in place. A hopper lined with firebrick is placed between the wall *a* and the flue sheet, and serves to collect the cinders that are pulled over the arch by the exhaust. A trap door *e* allows the cinders to be dumped.

OIL-BURNING FIREBOX

16. A sectional view of a firebox for burning oil is shown in Fig. 11. The firebox differs from that of a coal-burning

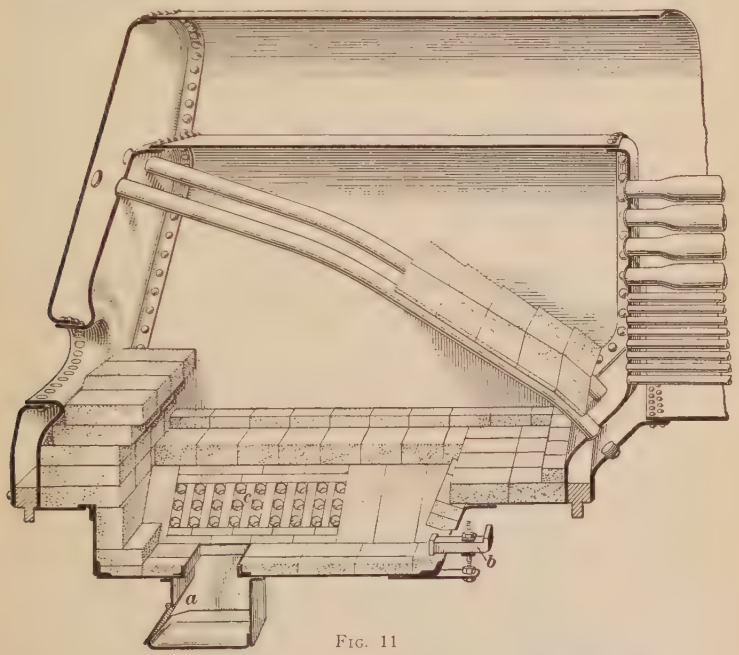

FIG. 11

locomotive in that the grates and ash-pan are not used. The grates are replaced by brick, and a hopper provided with a door *a* is used instead of an ash-pan. The sides of the firebox

are lined with firebrick to a point above the direct path of the oil jet, so as to protect the sheets against the intense heat of the jet. The oil, which is vaporized in the burner b, is thrown against the flash wall at the back of the firebox. The air is supplied through the air holes c and also through the hopper door when it is opened and through a specially shaped fire-door.

JACOBS-SHUPERT FIREBOX

17. Fig. 12 shows a Jacobs-Shupert, or sectional, firebox sectioned in such a way as to make its construction easily understood. This type of firebox is designed to avoid the staying of the firebox sheets with staybolts, with the exception of the door sheet and the back tube-sheet. As the term sectional implies, the roof sheet, crown sheet and side-sheets of this type of boiler are made up of dished, or channel-shaped, sections a, which are supported by the staysheets a_1. The staysheets are placed between the sections, and the sections and the staysheets are then riveted together as shown at a_2 and a_3. The staysheets over the crown sheet are cut away to allow for a free circulation of the water, the parts removed being replaced by sling stays a_4. The holes a_5 in the part of the staysheets in the water legs are provided for water circulation. The upper part of the back boiler head is stayed by the back-head braces a_6.

18. On account of the irregular outline of the crown sheet and the side sheets, and the absence of staybolt beads, the available heating surface of the hottest part of the firebox is increased without the necessity of enlarging the grate area. A firebox constructed in sections, as this is, offers much more resistance to collapse in case the sheets become overheated than when the sheets are held up by staybolts, which when overheated pull through the holes. A Jacobs-Shupert firebox box can be applied to any type of boiler, the only requirement being that the dome be placed ahead of the firebox, as the construction of the sections prevents it from being placed over the firebox.

Fig. 12

BELPAIRE FIREBOX

19. Description.—In Fig. 13 is shown a cross-sectional view of a Belpaire firebox. The difference between this and other types of fireboxes lies in the shape of the roof sheet and the crown sheet, the Belpaire firebox being designed so that the crown sheet *a* and the roof sheet *b* are comparatively flat and parallel with each other. With this arrangement the radial, or crown, stays *c* are at right angles to both of the sheets, and this is a very desirable feature in staying flat surfaces under pressure. The upper section of the roof sheet is still further stayed by transverse rods *d*, which are placed at intervals in the steam space and are securely fastened at the ends. The Belpaire firebox gives an increased steam space due to enlarging tne upper part of the boiler.

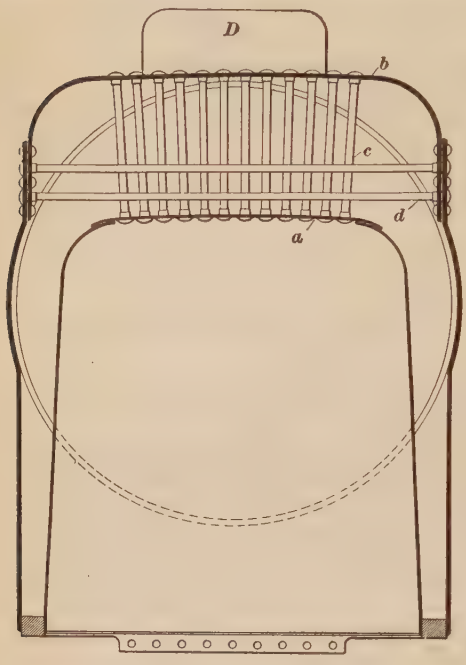

FIG. 13

The cylindrical part of the boiler in front of the firebox does not differ from any other type, and may be straight-top, extended-wagon, or conical. However the steam dome *D* is always placed on one of the courses in front of the firebox, because, on account of the flat surface, it cannot be very well placed over the firebox.

BOILER DETAILS

TUBES AND FLUES

20. The tubes and flues connect the back and the front tube-sheets, and are used to convey the products of combustion from the firebox to the smokebox. They also break the hot gases into small columns so that the heat is more readily transmitted to the water which surrounds them. The term *flues* is applied to those tubes which contain the superheater units, and the term *tubes* to all the others. The tubes and flues are fitted into holes that are drilled in the front and the back tube-sheets, and they also act as stays for these sheets. Tubes and flues are either of lap-welded or of seamless construction. Lap-welded tubes are made from strips of highly refined charcoal iron, or steel bent to shape and lap-welded at the joint. Seamless tubes are drawn from a block of refined iron or steel by special machinery which produces a tube without seams.

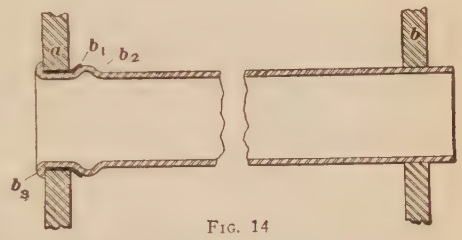

FIG. 14

21. The tubes used in locomotive boilers are generally either 2 inches or $2\frac{1}{4}$ inches outside diameter. Experience and experiments have proven that these sizes are the most desirable. If smaller sizes are used, the tendency is for the tubes to become stopped up, while increasing the size decreases the total tube heating surface and reduces the capacity of the boiler to generate steam. Small tubes have a greater heating surface in proportion to the volume of gases passing through them than do large ones, because the small tubes break the hot gases into smaller columns and thus utilize more of the heat, and the hot gases escape to the smokebox at a lower temperature

22. Application of Tubes.—The tube holes in the tube-sheets are drilled to size before the sheets are put in place. The holes in the front tube-sheet b, Fig. 14, are drilled $\frac{1}{16}$ inch larger than the hole in the sheet so that the tube can slip freely through it. The firebox end of the tube is swaged down to a slightly smaller diameter than the tube hole, so as to allow a copper ferrule b_1 to be inserted in the hole between the sheet and the tube. The ferrule is a piece of copper pipe $\frac{1}{16}$ inch in thickness and $\frac{3}{4}$ inch long and is rolled lightly in the hole before the tube is inserted. The tube extends about $\frac{3}{16}$ to $\frac{1}{4}$ inch beyond the face of the sheet into the firebox and is rolled tight against the ferrule and the sheet by means of roller expanders. The tube is then expanded by sectional expanders to bell it out on the inside as shown at b_2. The end which extends beyond the sheet is then turned over and beaded down firmly, as shown at b_3 by use of a beading tool of special form.

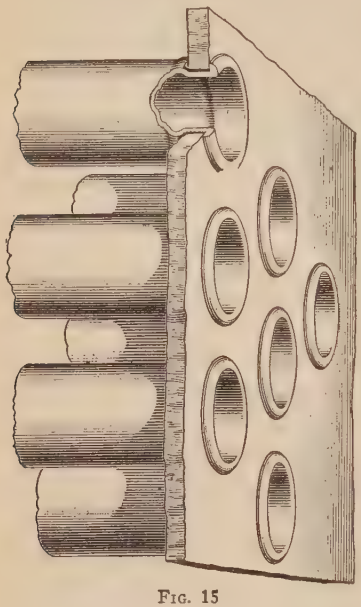

FIG. 15

23. By this method, the tube, in addition to being securely rolled in place, is clinched against the sheet on both sides, and therefore makes a strong joint. The ferrule b_1 is placed flush with the face of the sheet on the fire side and serves to make a tight joint between the tube and the sheet, because when the tube is expanded the ferrule, being soft, will fill completely any opening between the tube and the tube hole. The ferrule also prevents the tube from leaking, because it expands at a low temperature and therefore is not affected by a variation in temperature to such an extent as the tube and tube-sheet.

Fig. 15 is a section of a tube-sheet and shows how the tubes appear when they are beaded over on the firebox side.

The tubes are rolled at the front tube-sheet *b*, Fig. 14, in the same manner as at the back tube-sheet, but the sectional expander is not used and the tubes, depending on local conditions and practice, may or may not be beaded as shown at b_3 on the other end. Generally it is considered unnecessary to bead them, as there is little chance of the ends of the tubes being burned off as in the case of the firebox end. Copper ferrules are seldom used in the front tube-sheet.

The small tubes are sometimes welded to the tube-sheet, in which event the copper ferrule is omitted. The tube is not swaged, and after rolling, the edge is chipped off and then welded in much the same way as a superheater flue, the application of which is described farther on.

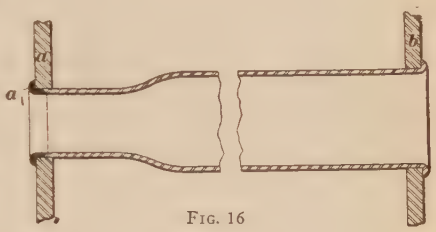

Fig. 16

24. Superheater Flues.—When the fire-tube superheater is installed in a locomotive boiler, it is necessary to increase the size of some of the tubes to make provision for the superheater units which are placed in them. To permit the installation of the units and still have sufficient space for the hot gases to pass through and circulate around the units, the tubes, or flues as they are generally called, are made $5\frac{3}{8}$ or $5\frac{1}{2}$ inches outside diameter with the firebox end at *a* swaged down to $4\frac{3}{8}$ to $4\frac{5}{8}$ inches, as shown in Fig. 16. The reduction in size at the firebox end is to allow a better circulation of water around the flues near the back tube-sheet and also to give added strength to the bridges in the back tube-sheet.

25. Application of Superheater Flues.—In the application of superheater flues, the flues are beaded at both ends, as shown in Fig. 16, so that they may be more securely held in position. In some cases ferrules are used at the firebox end *a*, the same as with the small tubes, while in other cases they

are omitted. It is considered good practice when the ferrule is omitted to weld the flue and the sheet together at the firebox end, electric-arc welding being preferred. To do this, the end of the flue is slightly beveled off and a bead is welded entirely around it as shown at a_1, Fig. 16. In some cases the entire tube and flue installation is welded at the firebox end. This method has been found to give excellent results, as it saves much tube and flue trouble and engine failures from leaky tubes. The success of this practice, however, depends largely upon local conditions and the section of the country in which the locomotive is working.

When superheater flues are used, the small tubes immediately around the flues are also beaded at the front end.

26. Number of Tubes.—The number of tubes in a locomotive boiler varies from 180 to 400, while the number of superheater flues varies from 18 to 70.

The thickness of a 2- or $2\frac{1}{4}$-inch tube, lap-welded or seamless, is about .125, or $\frac{1}{8}$, inch, and this gives an internal diameter of $1\frac{3}{4}$ or 2 inches, as the case may be. The thickness of a $5\frac{1}{2}$-inch superheater flue is about $\frac{5}{32}$ inch. Standard specifications require that the finished tubes and flues shall be circular within .02 of an inch and shall not vary more than .015 of an inch, outside diameter, from the size intended. Also, that tubes under 5 inches outside diameter shall be tested to 1,000 pounds per square inch hydrostatic pressure, while tubes or flues over 5 inches in diameter shall be tested to 800 pounds per square inch hydrostatic pressure.

THE STEAM DOME

27. Description.—The steam dome is a cylindrical receptacle on the top of the boiler, and is used for collecting and holding dry steam. It is usually placed on the boiler course in front of the firebox, although with the smaller and older types of boilers the steam dome was placed directly over the crown sheet. As is shown in the sectional view, Fig. 17, the steam dome is made up of a cylindrical barrel a,

which has a double-riveted butt joint on one side, not shown, a heavy flanged collar *b* to which the barrel is riveted, and a

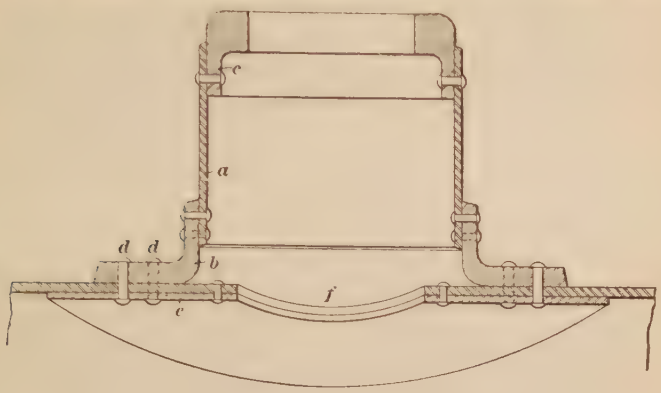

Fig. 17

cast-steel ring *c* to which the cover, not shown, is secured by bolts. The dome may also be made in one piece, as shown in Fig. 18, by pressing it to shape in a flanging press. This method eliminates the riveting in the butt joint and also in the collar and ring. The dome, whether built up or in one piece, is riveted to the boiler shell by a double row of rivets *d* which

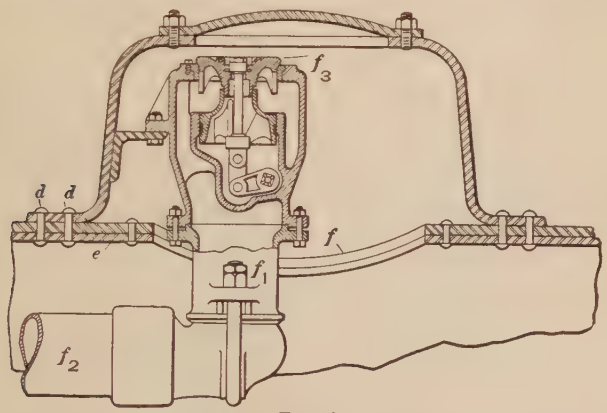

Fig. 18

extend through the dome base, the boiler shell, and the dome liner *e*. The liner is necessary to strengthen the boiler shell

which is weakened by the cutting of the large hole f in the plate. This hole, Fig. 18, permits dry steam to enter the dome and also provides an opening for the throttle pipe f_1 which connects to the dry pipe f_2. The throttle valve f_3 controls the passage of steam from the dome to the throttle pipe and dry pipe.

28. The hole f also provides an opening through which a man may enter the boiler to inspect the interior or to make necessary repairs, and it is the only opening in the boiler that is large enough for this purpose. The opening f should not be made larger than is absolutely necessary, because its size seriously affects the strength of the shell, the larger the opening the weaker the shell, other things being equal.

The dome cover which closes the opening on the top of the dome should be kept reasonably small, as the only method of staying is by bolting it to the outer edge of the ring or to the inner edge of the dome, if a one-piece dome is used.

Domes are made about 2 feet 6 inches in diameter and from 12 to 36 inches high. The size of the dome depends on the size of the boiler and the clearance of the right of way, the latter preventing the use of a high dome on large boilers. The dome, being the highest point above the surface of the water, is an ideal place in which to place the throttle valve; for to reach it there the steam must travel farther before it enters the valve and this insures dryer steam because the steam is more thoroughly relieved of any water that may be entrained in it.

29. In boilers of very large capacity, an extra dome, called an auxiliary dome, is sometimes used to which the safety valves and the whistle are attached. In such case the dome that contains the throttle valve can be located nearer the front end. This arrangement is an advantage with long boilers because the length of the dry pipe is reduced.

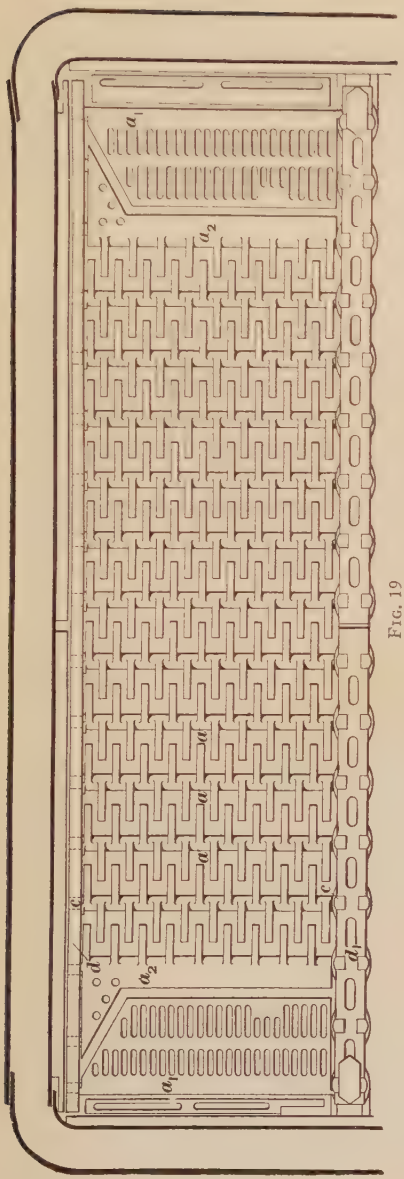

Fig. 19

GRATES

30. Description. The grates usually consist of a set of parallel bars called grate bars, made of cast iron, and placed at the bottom of the firebox. The purpose of the grates is to hold the fuel as it is being burned.

Grates are classified as rocking, or shaking, grates; dead, or dump, grates; and corner grates. In Fig. 19, which shows one-half of a section of grates, the rocking grates are marked a, the dump grates a_1, and the corner grates a_2. The shaking grates have trunnions c on the ends of the grate bars which are carried by the grate bearers d and d_1.

Rocking or shaking grates, which are shown in section in Fig. 20, consist of a series of flat, or finger, grate bars. These grate bars can be turned out of a horizontal position by a system of arms b which are pinned to the projections f on the lower side of the grate bars. The arms b are connected by arms b_1 to levers d, which extend

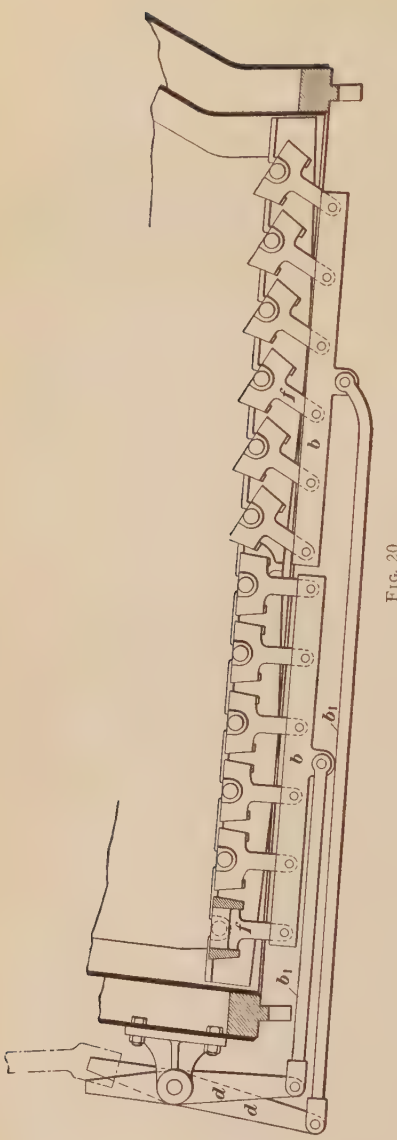

Fig. 20

through to the cab deck and are attached to brackets on the back head. The grates are turned by applying a bar to the lever *d*, as shown, or by means of mechanical shakers, if the grates are very large.

31. The grate bars are connected up in sections to the arms *b*, and therefore one section of the grates can be moved independent of another section. Care should be taken not to connect too many sections to the same arm, as difficulty will then be experienced in shaking the grate.

As shown in Fig. 19, a finger grate bar is constructed with projections or fingers on each side, which come between the fingers on the grate bar next to it. When the grates are rocked or turned, the fingers of one grate bar disengage with the fingers of the next and allow the ashes to fall through into the ash-pan. A flat shaking grate has no fingers.

32. Corner grates a_2, Fig. 19, have square trunnions instead of round, and are set stationary in place.

They are not connected with the shaking or rocking grates. Drop, or dump, grates a_1 are of large size and are so arranged that they can be dropped independently of the other grates. Their use allows large clinkers as well as ashes to be dumped into the ash-pan. Dump grates are usually placed at the back, and sometimes at the front of the firebox as shown.

In narrow fireboxes, the grate bars extend entirely across the box and are supported by grate bearers bolted to the side sheets. The bearers are so set that the top of the grate bars will at least be level with the top of the foundation ring or slightly above it. In wide fireboxes a center bearer d_1 is located in the center of the firebox and serves the same purpose as the side bearer. The use of a center bearer permits the grate bars to be made shorter and lighter and thus more easily handled.

In designing grates, the object is to secure the largest possible amount of air space between the grate bars and at the same time prevent unburned coal from falling through into the ash-pan.

The grate area is expressed in square feet and is obtained by multiplying the total length of the grate in feet by their width.

ASH-PAN

33. The ash-pan is a receptacle placed under the firebox for the purpose of collecting and holding the ashes which drop or are dumped through the grates. Ash-pans should be constructed so as to prevent, as far as possible, live coals from dropping through and starting fires along the right of way.

Fig. 21 shows an exterior view of the side of an ash-pan used with a wide firebox. The principal parts of an ash-pan are the receptacle proper, an arrangement for dumping the ashes, and in some cases dampers to control the admission of air to the fire. Ash-pans are made in a large number of different styles and shapes, depending on the size of the firebox, the wheel arrangement of the locomotive and the service in which the locomotive is used.

The size of the firebox materially affects the type of ash-pan used, as the pan must extend under the entire grate surface.

34. The ash-pan shown in Fig. 21 is made up of two hoppers *a*, hence the term *hopper ash-pan*. The hopper arrangement is necessary because the trailing wheels come in about the center of the pan. The bottoms of the hoppers are closed by cast-iron doors a_1, which may be operated by a series of levers from the cab or by a compressed-air apparatus. The hoppers have a width of 24 to 30 inches at the bottom and gradually extend upwards and outwards to the foundation ring *m*. The sides of the pan extend up over the frames to a point level with or slightly above the bottom of the ring.

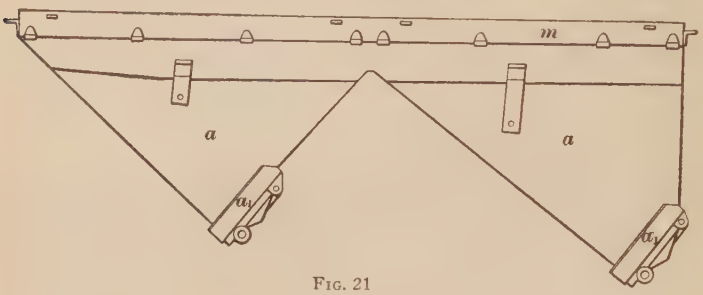

FIG. 21

In some cases the pan is attached directly to the ring, and in others a space of from 3 to 5 inches is left between the pan and the ring so as to provide a space through which air can enter to the under side of the grates. When the sides of the pan are bolted directly to the ring, pockets or perforated plates are inserted along the sides and also at the ends of the pan to provide the necessary air inlets. The preferred way is to have the air inlets at the top of the pan away from the ashes.

35. When very wide fireboxes are used, the ash-pan may have a series of hoppers between the frames and also on the outside of the frames on each side, but the principle of construction is the same as already described.

On account of the numerous classes of locomotives, there is no one style of ash-pan that can be considered as a standard.

Nearly all the large railroad companies have adopted styles to suit their own special purpose.

By orders of the Interstate Commerce Commission, all ash-pans must be equipped with some device whereby they can be cleaned or dumped without the necessity of going under the engine to do it. The means provided for this purpose are operated from the cab either by hand, air, or steam, at the convenience of the engineer. The hoppers and the hopper doors are made of cast steel or malleable iron. The plates used in the construction of the rest of the pan are usually $\frac{1}{4}$ inch, or $\frac{5}{16}$ inch thick. Some pans are made of one piece of cast steel but this practice is not general.

36. Air Inlets in Ash-Pan.—The area of the air inlets in ash-pans varies on account of the different grate areas and the quantity of air required to burn the various kinds of coal. The area of the air inlets for average bituminous coal should be 14 to 18 per cent. of the grate area. For anthracite coal, the air inlets should be increased, or the area should be from 15 to 35 per cent. of the grate area. Because of the very limited space in which it must go, it is a somewhat difficult problem to construct the ash-pan so that there will be adequate air space and at the same time sufficient material or strength left to carry the weight of the ashes.

CIRCULATION IN BOILERS

37. Importance of Circulation.—Circulation in locomotive boilers is the name given to the motion of the water under the influence of heat. The water nearest to the source of heat is heated and expands, and thereby becomes lighter and rises to the top. As this water rises to the surface, other cooler water will take its place, become heated, and also rise. This continual movement of the water is called *circulation*. The circulation of the water keeps the heating surfaces covered with water at all times and thus prevents any part from becoming overheated or burned. Circulation secures regularity and steadiness in the generation of steam,

tends to equalize the temperature throughout the boiler, and prevents unequal expansion and consequent straining of the different parts. The circulation of the water tends to maintain the greatest possible difference of temperature between the water on one side of the plates and the hot gases

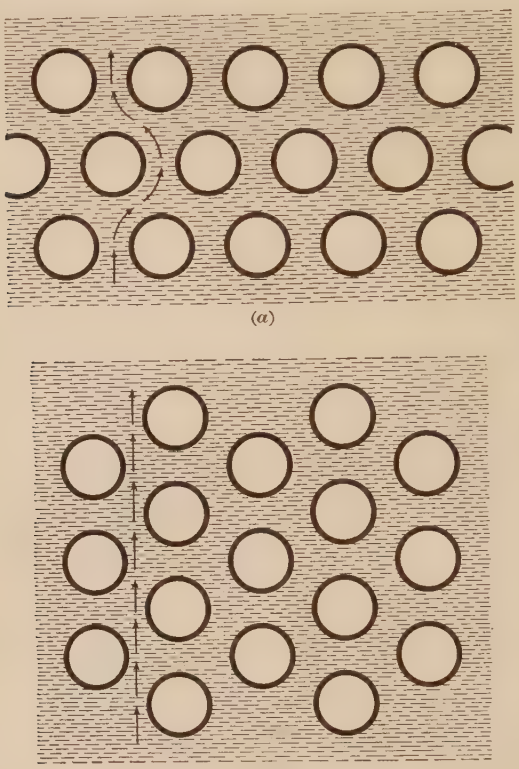

Fig. 22

on the other side, thus enabling the heat to be absorbed readily. In addition, circulation tends to keep the heating surfaces as clear of mud and other deposits as possible. The more rapid the circulation, the greater the amount of heat that will be transferred from the firebox and tubes to the water.

38. Advantages of Proper Circulation.—The advantages derived from proper circulation may be summed up as follows: The boiler is kept cleaner, and this means that more water will be evaporated per pound of fuel, which results in a saving of coal. There are less strains on the boiler due to unequal expansion and contraction, and there is less corrosion and pitting of the sheets.

39. Circulation of Water.—The circulation of water in a locomotive boiler is shown in Fig. 2. The heated water from around the firebox rises to the surface and takes steam bubbles with it. The cooler water from the front of the boiler, where nearly all feed-water inlets are located, flows back to take the place of that which has moved upwards. In this way a circulation of water is maintained in the general direction indicated by the arrows.

40. Influence of Tube Spacing on Circulation.—In locomotive boilers, the large number of tubes and flues makes it important that they shall be so spaced as to interfere as little as possible with the circulation of the water around them. There are two methods of arranging the tube spacing in boilers. In Fig. 22 (*a*) is shown what is called zig-zag spacing, and view (*b*) shows vertical spacing. The method shown in view (*b*) is more generally used, because, as shown by the arrows, there is less obstruction to the steam bubbles as they rise to the surface than with the arrangement shown in view (*a*).

HEATING SURFACE

41. Definition.—The heating surface of a locomotive boiler is that part of the boiler that is exposed to the direct heat of the fire or the gases of combustion on one side, and which has water available for evaporation on the other side.

42. Kinds of Heating Surfaces.—Heating surface is usually divided into firebox heating surface and tube and flue heating surface. The firebox heating surface consists of the sheets of the firebox above the grate level, and comprises the

crown sheet, the side sheets, the door sheet less the area of the door hole, and the back tube-sheet less the internal area of the tubes and flues. Tube or flue heating surface comprises the total outside surface of the tubes and flues between the front and the back tube-sheets. The area of the front tube-sheet is not taken into consideration in calculating the heating surface. Heating surface is usually expressed in square feet.

43. Efficiency of Heating Surface.—The efficiency of the heating surface depends upon the following factors: The location of the heating surfaces, the condition of the surfaces, and the arrangements by which the water has rapid and free circulation throughout the boiler. The location of the heating surface has an important influence; for the surface in direct contact with the fire will evaporate water at a much higher rate than an equal amount of heating surface that is not in direct contact with the fire, such as the tube heating surface.

If the tubes and flues become coated with scale on the water side or are partly or entirely plugged with soot on the fire side, the ability of these surfaces to conduct heat to the water is reduced, and the efficiency of the surface is lowered because it does not evaporate the amount of water that it should.

44. The location of the entry of the feed-water may be such as to hinder proper circulation. The tubes and flues may be placed too closely together, in which case the water may be retarded from coming in contact with the proper heating surfaces; thus the rate of evaporation and hence the efficiency of the surface will be lowered.

Of the different heating surfaces of the boiler, the crown-sheet surface is the most effective, then that of the side, tube, and door sheets in the order named, and the tube and flue surfaces last. In calculating the evaporation values, all the sheets of the firebox are taken at the same rate, likewise the rate for the tubes and flues is taken as the same.

45. Direct and Indirect Heating Surfaces.—The heating surface of the firebox sheets and arch tubes is termed

the direct heating surface, as these parts are subject to the direct action of the fire. The surfaces of the tubes and flues are called the indirect heating surfaces because these surfaces are only exposed to the heat of the gases that have passed out of the firebox. The sum of the direct and indirect heating surfaces is the total heating surface of the boiler.

BOILER PROPORTIONS

BOILER EVAPORATION

46. Firebox Evaporation.—Tests have shown that the evaporation in a modern locomotive firebox is equal to about 55 pounds of steam per hour for each square foot of firebox

TABLE I

EVAPORATION FROM TUBES AND FLUES IN POUNDS OF STEAM PER HOUR PER SQUARE FOOT OUTSIDE SURFACE

Length Feet	2-Inch Tubes			2¼-Inch Tubes				5¾- and 5½-Inch Flues		
	Spacing—Inches			Spacing—Inches				Spacing—Inches		
	5/8	3/4	7/8	5/8	3/4	7/8	1	3/4	7/8	1
14	9.80	10.36	10.82	10.39	10.88	11.30	11.69	12.04	12.17	12.30
15	9.44	9.97	10.42	10.02	10.51	10.92	11.29	11.65	11.78	11.90
16	9.10	9.60	10.05	9.67	10.15	10.55	10.90	11.28	11.40	11.52
17	8.78	9.27	9.69	9.34	9.80	10.19	10.53	10.94	11.06	11.16
18	8.47	8.95	9.35	9.03	9.46	9.85	10.18	10.60	10.72	10.82
19	8.18	8.63	9.02	8.73	9.12	9.51	9.84	10.29	10.40	10.51
20	7.90	8.32	8.70	8.44	8.83	9.18	9.51	10.00	10.10	10.22
21	7.63	8.02	8.40	8.15	8.55	8.89	9.19	9.72	9.83	9.94
22				7.90	8.28	8.61	8.90	9.44	9.55	9.66
23				7.66	8.03	8.35	8.62	9.18	9.29	9.38
24				7.42	7.78	8.08	8.35	8.94	9.04	9.12
25				7.20	7.55	7.85	8.10	8.70	8.80	8.90

heating surface. As it requires a pound of water to generate a pound of steam, 55 pounds of water is converted into steam for each square foot of firebox heating surface per hour. The heating surface of the arch tubes and the combustion chamber is included in the firebox heating surface.

47. Tube and Flue Evaporation.—The quantity of water evaporated by the tubes and flues varies with their length, diameter, and spacing. By *spacing* is meant the space between the tubes proper and not between the beads.

Table I, which was prepared by the American Locomotive Company, shows the evaporation from tubes and flues in pounds of steam per hour per square foot of outside surface. The evaporation is given for tubes and flues from 14 to 25 feet in length and 2 inches, $2\frac{1}{4}$ inches, $5\frac{3}{8}$ inches, and $5\frac{1}{2}$ inches in diameter. The different spacing of the tubes and flues is as shown in the table.

The following illustrates the use of the table: Let it be assumed that it is required to know the number of pounds of

TABLE II

OUTSIDE HEATING SURFACE OF TUBES IN SQUARE FEET

Outside Diameter of Tubes Inches	Area of End Square Inches	Length, In Feet											
		14	15	16	17	18	19	20	21	22	23	24	25
2	3.14	7.33	7.85	8.37	8.90	9.42	9.94	10.47	10.99	11.51	12.04	12.56	13.09
$2\frac{1}{4}$	3.97	8.24	8.83	9.42	10.00	10.60	11.19	11.78	12.37	12.95	13.54	14.13	14.72
$5\frac{3}{8}$	22.69	19.70	21.10	22.51	23.92	25.32	26.73	28.14	29.55	30.95	32.36	33.77	35.17
$5\frac{1}{2}$	23.76	20.15	21.59	23.03	24.47	25.91	27.35	28.79	30.23	31.67	33.11	34.55	35.99

steam that will be evaporated in 1 hour from each square foot of tubes 17 feet long having a diameter of 2 inches and spaced $\frac{3}{4}$ of an inch apart. In the first column of the table, is found the length, 17 feet. Opposite this, in the column for $\frac{3}{4}$-inch spacing under the head 2-Inch Tubes, is 9.27, the number of pounds of steam evaporated per hour by 1 square foot of heating surface.

48. Calculating Tube and Flue Evaporation.—The amount of steam that each square foot of a tube or flue will evaporate in one hour having been determined it is a simple matter to calculate the total evaporation of a tube or flue. It is only necessary to find the total outside heating surface as shown in Table II, and multiply by the evaporation per square foot as shown in Table I.

49. Table II gives the total outside heating surface of the tubes and flues of the lengths and diameters shown in Table I. The heating surface is given in square feet. Thus a 2-inch tube, 18 feet long, has an outside heating surface of 9.42 square feet.

Let it be assumed that it is required to find the evaporation per hour of a tube 20 feet long, 2 inches in diameter, with a spacing of $\frac{3}{4}$ inch. Table II shows that the outside heating surface of the tube is 10.47 square feet. Table I shows that each square foot of this tube will evaporate 8.32 pounds of steam per hour. Therefore the tube will evaporate 10.47×8.32 or 87.12 pounds of steam per hour. This multiplied by the total number of the tubes gives the total steam evaporation of the tubes per hour. If superheater flues are used, their heating surface and evaporation can be calculated from Tables I and II in the same way as the tubes.

Slightly more accurate results will be obtained by subtracting the thickness of the front and back tube-sheet from the length of the tube. The thickness of the two sheets can be assumed as being equal to 1 inch.

50. Calculating Firebox Evaporation.—The quantity of steam in pounds evaporated per hour by the firebox is equal to the number of square feet in the firebox heating surface mutliplied by the evaporation per square foot, which is 55. When calculating the heating surface of the firebox, it is necessary to deduct the combined area of the ends of the tubes and the flues from the area of the tube-sheet. Also the area of the door hole should be deducted from the area of the back sheet.

The area of the ends of the tubes and flues in square inches of the sizes given in Table I is shown in the second column of Table II.

51. Total Evaporation.—The total steam evaporated in pounds per hour will be the sum of that evaporated by the firebox heating surface and the tube and flue heating surface.

STEAM AND COAL USED PER HORSEPOWER

52. Cylinder Horsepower.—The cylinder horsepower of a saturated-steam or superheated-steam locomotive can be obtained from the following rule:

Rule.—*To calculate the cylinder horsepower of a saturated-steam locomotive, multiply the cross-sectional area of one cylinder in square inches by the boiler pressure and by .0212. For a superheated-steam locomotive, multiply the cross-sectional area of one cylinder by the boiler pressure and by .0229.*

EXAMPLE.—The cylinders of a superheated-steam locomotive are 28 inches in diameter and the boiler pressure is 180 pounds. What is the cylinder horsepower?

SOLUTION.—The cross-sectional area of one cylinder is $28\times28\times.7854 = 615.8$ sq. in. The cylinder horsepower is $615.8\times180\times.0229 = 2{,}542$ H. P. Ans.

53. Steam Required Per Horsepower.—Tests have shown that the development of 1 cylinder, or engine, horsepower for 1 hour requires 27 pounds of steam for a saturated-steam locomotive and 20.8 pounds of steam for a superheated-steam locomotive. The term horsepower hour is applied to the development of 1 horsepower for 1 hour. Hence, the steam required per hour is equal to the horsepower multiplied by 27 for saturated steam and by 20.8 for superheated steam.

EXAMPLE.—How much steam is required per hour for a superheated-steam locomotive of 2,000 cylinder horsepower?

SOLUTION.—Each horsepower requires 20.8 lb. of steam, hence the total pounds of steam for 1 hour is $2{,}000\times20.8 = 41{,}600$ lb. Ans.

54. Coal Required per Horsepower Hour.—One pound of bituminous coal will generate $6\frac{3}{4}$ pounds of steam in average service. As already shown, 1 horsepower can be obtained from 27 pounds of saturated steam. Therefore, the amount of coal required per horsepower hour for saturated steam is 27 divided by $6\frac{3}{4}$, or 4 pounds. The saving in coal due to superheating is 18.75 per cent., and 4 pounds, less 18.75 per cent., is 3.25 pounds. Hence, 3.25 pounds is the coal required per horsepower hour with superheated steam.

Therefore, the total number of pounds of coal required per hour is equal to the horsepower multiplied by 4 for saturated steam and by 3.25 for superheated steam.

55. Boiler Horsepower.—The boiler horsepower can be found from the following rule:

Rule.—*To find the boiler horsepower, divide the total evaporation by the pounds of steam required per cylinder horsepower hour. As explained in Art.* **52**, *this is 27 pounds for saturated-steam locomotives and 20.8 pounds for superheated-steam locomotives.*

EXAMPLE.—The total steam evaporated with a superheater locomotive is 39,600 pounds per hour. What is the boiler horsepower?

SOLUTION.—The boiler horsepower is equal to $\frac{39{,}600}{20.8} = 1{,}904$ H. P. Ans.

It is assumed in the foregoing problem that the total evaporation has first been calculated in accordance with Arts. **48** and **49**.

It is desirable to proportion the heating surface so as to make the boiler horsepower equal to the cylinder horsepower. However, it has been shown that a boiler horsepower in excess of the cylinder horsepower results in considerable economy in fuel and water.

DIAMETER OF SMOKESTACK

56. The diameter of the smokestack depends on the boiler horsepower. Hence, when the rule for determining the boiler horsepower is known, the diameter of the stack can be found.

In Table III are given the stack diameters for simple and compound, superheated and saturated-steam locomotives of various boiler horsepowers. This table gives the American Locomotive Company's standard practice. The stack sizes given in the table are for a stack having a taper of 1 inch in 12 inches. When the stack is straight, $1\frac{1}{2}$ inches is to be added to the diameters shown.

57. The rule for obtaining the diameter of the stack is as follows:

Rule.—*Obtain the boiler horsepower and use the nearest corresponding diameter of stack given in Table III.*

TABLE III

STACK DIAMETERS FOR COAL-BURNING LOCOMOTIVES

Stack Diameter Inches	Boiler Horsepower			
	Superheated		Saturated	
	Compound (Mallet)	Simple	Compound (Mallet)	Simple
12	1,000	920	860	750
12½	1,080	1,000	930	810
13	1,170	1,080	1,010	880
13½	1,270	1,170	1,090	950
14	1,370	1,260	1,170	1,020
14½	1,490	1,370	1,270	1,110
15	1,610	1,490	1,380	1,210
15½	1,750	1,620	1,500	1,310
16	1,900	1,750	1,630	1,420
16½	2,100	1,940	1,800	1,570
17	2,320	2,140	1,990	1,740
17½	2,570	2,370	2,200	1,920
18	2,820	2,610	2,420	2,120
18½	3,100	2,860	2,660	2,330
19	3,400	3,140	2,910	2,550
19½	3,720	3,440	3,190	2,790
20	4,070	3,760	3,490	3,060
20½	4,450	4,100	3,810	3,340
21	4,840	4,460	4,150	3,630

EXAMPLE.—The total steam evaporated with a simple superheated locomotive is 43,680 pounds. What should be the diameter of the stack?

SOLUTION.—From the rule in Art. **55**, the boiler horsepower is equal to $\frac{43,680}{20.8}$ = 2,100 H. P. The stack diameter by Table III is 16½ in.

CALCULATING THE GRATE AREA

58. Rate of Combustion.—The rate of combustion is stated in terms of number of pounds of coal burned per square foot of grate area per hour. If the grate area is 60 square feet, and if 3 tons of coal is burned in 1 hour, the rate of combustion is 100 pounds of coal per square foot of grate area per hour.

59. Grate Area Required.—For high-grade bituminous coal, containing about 14,000 British thermal units per pound, the maximum rate of combustion for economical evaporation has been found to be about 120 pounds per square foot of grate area per hour. Larger amounts than this have been burned, but careful tests show that such practice is wasteful of fuel and results in low evaporation per pound of coal.

For locomotives burning anthracite, the maximum economical rate of combustion is from 55 to 70 pounds per square foot of grate per hour, the quantity of coal burned varying according to the quality of the coal.

When the horsepower to be developed is known, the amount of coal that must be burned to produce it can be determined by the method explained in Art. **54**, where it was stated that horsepower $\times 4$ = pounds of bituminous coal required per hour for saturated steam, and horsepower $\times 3.25$ = pounds of coal required per hour for superheated steam.

The grate area required to burn the amount of coal required can then be found by dividing the total coal that must be burned per hour by the number of pounds that can be burned per square foot of grate area per hour. The rule, then, for finding the grate area is as follows:

Rule.—*To obtain the grate area, in square feet, for burning bituminous coal, divide the total coal to be burned, in pounds per hour, by 120. For anthracite, divide by a number varying from 55 to 70, according to the quality of the coal. The higher the grade of coal the larger the number used.*

EXAMPLE 1.—Find the grate area required for a saturated-steam locomotive burning bituminous coal, the diameters of the cylinders being 26 inches and the steam pressure 200 pounds to the square inch.

SOLUTION.—From the rule in Art. **52** the horsepower is $531 \times 200 \times .0212 = 2{,}252$, and the quantity of coal burned per hour, Art. **54**, is $2{,}252 \times 4 = 9{,}008$ lb. The grate area is therefore $\frac{9{,}008}{120} = 75$ sq. ft. Ans.

EXAMPLE 2.—Find the grate area required for a superheated-steam locomotive burning bituminous coal, the diameter of the cylinders being 28 inches and the boiler pressure 180 pounds to the square inch.

SOLUTION.—From rule in Art. **52**, the horsepower is $616 \times 180 \times .0229 = 2{,}542$. According to Art. **54**, the coal burned per hour is $2{,}542 \times 3.25 = 8{,}261.50$ lb. The grate area is therefore $\frac{8{,}261.50}{120} = 69$ sq. ft. Ans.

LOCOMOTIVE BOILER DESIGN

60. Principles of Design.—The design of the locomotive boiler and firebox and their appurtenances should be such as will permit of the greatest possible evaporation from a given amount of fuel. It is an advantage if the boiler capacity is equal to or in excess of the cylinder requirements. When this is the case, the maximum hauling capacity of the locomotive can be obtained even when working under somewhat adverse conditions.

In modern locomotive practice, all things are made subordinate to the boiler and the cylinders. Of these two, the boiler is first in importance, as the performance of the locomotive depends on the ability of the boiler to generate steam. If the boiler fails to supply the required amount of steam, the result will be a locomotive that will not haul the train without losing time, except with a reduced tonnage.

Again, a boiler may provide sufficient steam, but the grate area may be incorrectly designed and proportioned. In this event the locomotive will be wasteful of fuel.

In order that modern locomotives shall do the work required of them, it is necessary for the boiler to be properly constructed, for the firebox to be of sufficient size to produce the best possible combustion of the fuel, and for the grate area to be such that the fuel will be burned economically.

Reliable tests have shown that a square foot of firebox heating surface will evaporate about five times as much water

per hour as a square foot of tube heating surface. It is therefore an advantage to have a relatively large firebox heating surface.

The demand for heavy power has necessitated increasing the size of the boiler to such an extent that locomotive boiler design is a problem that requires careful study.

61. Of all steam-generating devices, the locomotive boiler is undoubtedly the most severely taxed as a structure. The reasons are as follows: The boiler cannot be perfectly insulated from cold; it must stand the effects of severe strains due to rapid and uneven heating up and cooling off while in service; it is subjected more or less to sudden cooling at the ash-pit and on the way from the ash-pit to the engine house; and, when required for service, steam is very often raised quickly, thereby causing very rapid expansion and the setting up stresses that ultimately will cause rupture of some part.

62. Design for Withstanding Pressure.—When it is required to confine liquids and gases under pressure, the ideal shape of the container is spherical. When it is impracticable to use a spherical container, the next in order of strength is one of cylindrical shape with spherical ends. With the same thickness of material, a cylinder with spherical ends will withstand a greater internal pressure than one with flat ends. A locomotive boiler has the shell cylindrical, but it is not possible to have the ends made spherical. This difficulty is overcome largely by having both ends, or the front tube-sheet and the back head, securely stayed to the shell, in which case the boiler nearly approaches the ideal for holding pressure. The firebox, however, with its flat surfaces, is poorly designed to withstand pressure, and for this reason it requires careful staying.

CONSTRUCTION OF BOILERS

63. Principles of Construction.—Two of the fundamental principles in boiler construction are, the boiler must be constructed so that it will withstand a pressure considerably in excess of the working pressure, and the construction should be such as to prevent disastrous results if the boiler should explode through neglect or carelessness.

The art of boiler making has been developed to such an extent that it is possible to build boilers that will withstand the high pressures now required with less danger of explosion than existed with the lower pressures that were used with the older types.

64. Order of Construction.—The construction of a locomotive boiler may be divided into a series of operations which briefly are as follows: (1) Procuring and testing materials; (2) laying out or marking off the sheets or plates; (3) punching the plates; (4) rolling or bending the plates to shape and flanging the plates that require it; (5) machining the plates, such as drilling the tube and flue holes, etc.; (6) assembling the several pieces; (7) riveting; (8) applying staybolts and stays; (9) calking all joints; (10) testing.

65. Materials.—The materials used in the construction of locomotive boilers are wrought iron, mild steel, and cast steel. Mild steel is used almost exclusively for the shell, heads, and firebox sheets. Tubes and flues are made from mild steel or highly refined iron, and staybolts and stays from refined iron or mild steel. The foundation ring is made of cast steel or wrought iron.

The steel used in boiler construction must be of the best quality obtainable, and should be designated and marked either as *flange steel* or *firebox steel*. Plate stamped by the manufacturer with either of these designations and also with the tensile strength of the piece is usually accepted as being made in accordance with the requirements of Federal and state laws governing the manufacture of plate. The plates should have a tensile strength, that is, a resistance to the

pulling apart of the particles, of not less than 55,000 pounds per square inch, and not more than 65,000 pounds per square inch.

Wrought iron, mild steel, cast steel, and refined iron used for the details of the boiler should be in accordance with standard practice and the laws governing it. All iron and steel should be free from seams and mechanical defects and should show a uniformly fibrous structure throughout.

66. Laying Out Plates.—The first step in the construction of a boiler after the plates are received is to lay out or mark off the different parts that go to make up the boiler. These parts consist of one or more cylindrical courses; the taper, or conical, course if there is one; the front and back tube-sheets; the door sheet; the throat sheet; the side and crown sheets; the roof sheet; the back sheet, and the smokebox. Great care must be taken in the laying-out of the plates so that all rivet holes and staybolt holes are in proper alinement.

67. Punching, Flanging, and Rolling.—The sheets after they are laid out are taken to the punching machine where all holes for rivets, staybolts, etc., are punched. The plates are then trimmed to the required size and shape either by shearing, or burning off the surplus material with the oxyacetylene torch. The sheets that require flanging are then taken to the flange shop where they are flanged by hand or by a flanging press. The hand method consists of heating the sheet in short sections and turning the flange by hand on cast-iron blocks. With the flanging-press method, the sheets are heated, and then the flanging press by the use of specially formed dies, forms the flange by hydraulic pressure in one or two operations, depending on the shape of the sheet.

The method of flanging in a flange press is much superior to the hand method. With the press, the flanging is completed in one or two operations, and less stresses are set up in the metal than is the case when the work is done by hand, which requires repeated heating up and cooling off. The flanging method also saves considerable time, is much cheaper and gives a more uniformly flanged sheet. The sheets that require flanging are the front and the back tube-sheets, door sheet, throat

sheet, and back head. After the front and the back tube-sheets are flanged, they are taken to the drilling machine where the tube and flue holes are drilled in them.

68. The cylindrical courses and the taper and conical courses, after being punched and trimmed to size and shape, are taken to the rolls where they are rolled to a circular shape. It is very important that these sheets be rolled to a perfect circle as otherwise the action of the pressure when the boiler is under steam will tend to force the sheet into a circle. This action is liable to start the seams and joints and may result in a leaky boiler.

This is especially true of the construction of the longitudinal butt joints, where, unless care is exercised, a flattened surface will result by reason of the several thicknesses of plate being placed together. The inside firebox sheet and the roof sheet are finally rolled to conform to the shape of the firebox.

69. Assembling.—As all the sheets are now shaped, they are set up or bolted in their respective places. The barrel, or shell, is usually put together first. After being securely bolted together, all holes are reamed out to the required size of the rivets. The barrel is then taken to the riveting machine, where by hydraulic pressure the various sheets are riveted together under a pressure of from 75 to 150 tons. The firebox sheets are then assembled and riveted together in much the same manner, and the firebox is then placed in the shell in its proper place in relation to the rest of the boiler. At this time, the holes for the staybolts that support the flat surfaces of the firebox are tapped out and the staybolts inserted and riveted over at the outer ends, if stays of the type requiring riveting are used. The stayrods that support the back head and the front tube-sheet are also fitted and riveted to the outer shell. The various sheets being now assembled and all rivets and staybolts in place, the seams or joints are made steam-tight, or *calked*, as it is called, by means of a calking tool held in a pneumatic hammer. The tubes and flues are inserted in place, and rolled, expanded, and beaded or welded. On the completion of this, the boiler is ready to be tested.

CARE OF BOILERS

70. Low Water. — The efficiency of a locomotive boiler depends largely upon the care it receives. It is of first importance that those in charge see that there is at all times a sufficient quantity of water in the boiler to cover the crown sheet and thereby make it impossible for the sheet to become overheated.

The firebox sheets and the tubes are in contact with the fire, and they would become heated to the temperature of the fire if it were not for the water on the other side. The temperature of the water depends on the boiler pressure, and rarely exceeds 400° F. Therefore, while the sheets are in contact with the water they cannot greatly exceed this temperature, although the temperature in the firebox may exceed 2,500° F. which is about the fusing point of firebox steel. The heat in the firebox is conducted through the plate to the water and is absorbed, thereby preventing the sheet from heating to the temperature of the fire.

The crown sheet is the highest sheet in the firebox and it will be the first one to become dry in the event of low water. An overheated crown sheet invariably results in an engine failure or a boiler explosion.

When the water falls below the level of the crown sheet, there is no water to keep the sheet reasonably cool, and the metal becomes very hot on account of the intense heat of the fire. The sheet when heated to about 600° F. loses much of its strength and expands very rapidly, causing the staybolt holes to become enlarged. As the depth of the thread on the staybolts is only about $\frac{7}{100}$ of an inch, the bolts become loose in the holes with a very small amount of expansion. The pressure in the interior of the boiler then causes the sheet to sag down by pulling away from the stays.

71. If the pulling away of the sheet from the stays is gradual, the result may not be serious; for as soon as a few of the stayholes in the sheet open, the steam will escape into the firebox and relieve the boiler of pressure and also give warn-

ing of what has taken place. If the rupture occurs quickly, the result is usually a disastrous explosion.

The reason for the explosion is that the rupture causes the boiler pressure to reduce to atmospheric pressure, and as a result practically all the water in the boiler flashes into steam, the volume of which greatly exceeds that of the water. The capacity of the boiler cannot accommodate the increased volume of the steam, and the rupture will not permit it to escape fast enough to prevent an excessive rise in pressure, which causes parts of the boiler to give away.

72. The force of a boiler explosion depends on the size and suddenness of the rupture, the pressure, and the volume of water present in the boiler. The average boiler has approximately a capacity of 500 cubic feet below the crown sheet, and a steam space of 150 cubic feet. If such a boiler with a pressure of 200 pounds fails and suddenly reduces the pressure to that of the atmosphere within two seconds, it is estimated that the energy released will develop 690,000 horsepower.

The sheets of the firebox may also become overheated and fail from causes that prevent the heat of the fire from being transmitted to the water. If the transmission of the heat to the water is obstructed by scale or grease, or if the water is foamy and fails to absorb the heat, the plates will retain the heat and become overheated.

The least possible depth of water that can be safely carried on the crown sheet is 3 inches. Less water than this is not considered safe.

73. Clean Heating Surfaces.—Another important item in the care of a boiler is to see that all heating surfaces are clean on both the inside and the outside. The interior of the boiler can be kept reasonably clean by frequently washing it out. All the exterior heating surfaces should be kept clear of soot, etc., because such things obstruct the transmission of the heat. Tubes and flues that are plugged, or stopped up, will materially affect the steaming of the locomotive, because they not only reduce the effective heating surface but they also retard to a great extent the draft on the fire.

Tests have proven that with one-half of the superheater flues plugged, the performance of the locomotive was reduced to that of a saturated-steam locomotive, with an increase in fuel consumption of 25 per cent. It has also been shown that with one hundred small tubes plugged the increase in fuel consumption is nearly 50 per cent.

74. This shows that the cleaning of the tubes and the flues as well as the other heating surfaces should receive careful attention. To insure economical operation, the tubes and flues, especially the superheater flues, should be blown out at the end of each trip. In bad-water districts if the boiler is not washed out as frequently as it should be, scale will form a coating over the surfaces and is liable to cause serious trouble. If the scale should become very heavy, the heat will not be carried away by the water fast enough to prevent a rise in the temperature of the plate.

The increase in temperature beyond a certain limit will cause the plate to become more or less seriously distorted. Unless cared for and remedied promptly, the plate will be affected to such an extent as to make a rupture very likely.

75. Blowing Out.—In no case should a boiler be blown out with a full pressure of steam, because the sudden reduction of pressure is almost sure to cause excessive strains on parts of the boiler as well as cause scale to form on the heating surfaces. To blow out the water, the pressure should be reduced to about 20 pounds per square inch before the blow-off cock is opened. A boiler should not be refilled with cold water until it has cooled off, because the sudden contraction of the several parts is sure to result in leaky seams or tubes.

76. Use of Blower.—Care should be exercised in the use of the blower, especially in locomotives without a brick arch. The improper use of the blower draws an excessive amount of cold air into the firebox and directly against the tubes and the flues. When the fire is low, or when there are holes in it, the draft caused by the blower will cool off the firebox sheets and tubes. The contraction that results will usually

start the tubes leaking to an extent that will in some cases cause an engine failure.

The improper use of the blower will also cause leaks at the staybolts. It is at the ash-pit, however, that the most damage is done by the abuse of the blower. Usually those in charge of the dumping and the cleaning of the fire think more of their own comfort than the care of the boiler, and use the blower strong enough to take all smoke, gases, and fine ashes away from the firebox. This causes a strong current of cold air to pass through the firebox and into the tubes, and the sudden contraction of the various parts invariably causes leaky tubes.

77. Honeycomb.—Care should be exercised in the handling of a locomotive boiler that small masses of clinkers, called honeycomb, are not allowed to form on the firebox sheets, especially on the heads of the crown stays and on the ends of the tubes and flues. Honeycomb is caused by the foreign matter in the coal adhering to those parts of the firebox surfaces which are exposed to the direct action of the flames and which are not properly covered with water on the other side. The clinker should be knocked off with a long rod through the fire-door, as when on the tube-sheet it obstructs the flow of hot gases through the tubes and reduces their effectiveness the same as if they were plugged.

78. Even Firebox Temperature.—When firing, it is important that the fireman maintain a firebox temperature as near uniform as possible. This avoids the alternate rise and fall in temperature as the fire is first forced and then allowed to burn down. A high firebox temperature causes the tubes to expand rapidly, and when the cold currents of air strike them, they suddenly contract. The alternate expansion and contraction soon causes loose tubes and flues and, very often, engine failures.

With oil-burning locomotives, on account of the high firebox temperature when the engine is working, care should be taken to see that the dampers are immediately closed when the fire is reduced. This prevents cold air from striking the hot

surfaces of the firebox. The possibilities of damage to the firebox are much greater with an oil-burning locomotive than in the case of a coal burner.

79. Leaks.—All leaks in the firebox, especially around the foundation ring, should be repaired as soon as possible, because the leakage represents a considerable loss of fuel. The steam also has a tendency to unite chemically with the sulphur in the coal and attack the metal in the sheets. All steam leaks into the front end from the steam pipes and the superheater should be attended to promptly. The leakage of steam causes a cutting action that soon wears away the parts it comes in contact with, and also reduces the vacuum in the smokebox. The smokebox door and the steam-pipe connections through the smokebox should be as nearly air-tight as possible so as to prevent the air from entering the smokebox and destroying the vacuum created by the action of the exhaust.

WASHING OUT BOILERS

80. The washing out of a locomotive boiler is a most important item, as successful maintenance and boiler efficiency depend largely on the care that is taken in washing out. Nearly all water contains more or less impurities, which settle to the bottom when the water is boiled. In the case of a boiler, the impurities settle on the tubes and the firebox sheets or at the bottom of the water legs, and, unless removed promptly, soon cause the formation of a hard scale. The scale reduces the efficiency of the heating surface to a considerable extent, because the heat must penetrate the scale before it reaches the water. Tests have shown that a deposit of scale $\frac{1}{8}$ inch thick results in a loss of 15 per cent. of the fuel burned. Another result of scale, especially on the firebox sheets, is the liability of the sheet to become overheated and collapse.

Washout plugs are provided to facilitate the washing out of a boiler and are placed in the most advantageous places. One is placed at each outside corner of the firebox and in some cases midway on the side sheets. Two to eight washout plugs

are placed in the back head just above the level of the crown sheet. Two plugs are also placed in the front tube-sheet, so that the barrel of the boiler may be washed out. The washout plugs are from $2\frac{1}{2}$ to 3 inches in diameter.

81. To wash out the boiler, a suitable nozzle is inserted in the washout-plug holes, and water under a pressure of 20 to 50 pounds per square inch is forced through the various portions of the boiler. When scale is present, scrapers are introduced through the plug openings and the scale is loosened and washed out.

The interval between washouts depends largely upon the condition of the water used, but the Federal regulations require that boilers must be washed out not less frequently than once a month. In bad-water districts the periods between washouts may be reduced to a week. An accurate record should be kept of each washout, and the date and details of each individual case should be recorded.

TESTING OF BOILERS

82. Method of Test.—All locomotive boilers should be tested from time to time, the period being determined by Federal or state regulations and local customs and requirements. The Interstate Commerce Commission prescribes that every boiler before being put into service, and at least every 12 months thereafter, shall be subjected to hydrostatic pressure 25 per cent. above the working steam pressure. The Canadian regulations require the same testing pressure.

Water or hydrostatic tests show the presence and location of any leaks much better than any other method, besides being more easily applied, as no special apparatus is required other than a force pump. A hydrostatic test will not reveal any broken or defective stays other than those with telltale holes, nor will it reveal badly fitted or corroded plates or tubes, or any other similar defects, as they are generally on the inside of the boiler and hence cannot be seen. It is advisable as far as possible to make an internal and external examina-

tion after a hydrostatic test is applied. When this is done, any defects on the inside of the boiler will be revealed.

83. Making the Test.—The methods of making a hydrostatic test of a boiler differ slightly in various parts of the country. However, it is generally conceded to be good practice to apply two separate tests; namely, a cold-water and a hot-water test. With the cold-water test, the boiler is filled with water, care being taken that all the air is allowed to escape by opening some valve at the highest point of the boiler, such as the safety valve.

A force pump is then connected to the boiler by a reinforced flexible hose, the connection being usually made at a $\frac{3}{4}$-inch opening in the side sheet. The force pump is then started and the pressure is raised slowly until it reaches 100 or 125 pounds per square inch. The gauges should be carefully watched for a sudden drop in pressure, as this usually indicates the giving away of some part of the boiler or that some appurtenance is leaking. This test might be termed a preliminary test, and it serves several purposes other than that of ascertaining whether the boiler is safe for the full working steam pressure.

84. First, this test discloses any leaks, so that, if serious, they can be remedied before the maximum testing pressure is applied. Second, it permits those in charge of the test to decide whether it is advisable to continue with the test; and third, it eliminates an unnecessary waste of heat in the useless heating up of a boiler on which a satisfactory test could not be obtained.

If the cold-water test proves satisfactory, the boiler is then heated. This may be accomplished by allowing live steam to enter the boiler, or by a portable oil blower which is placed in the firebox and withdrawn after the boiler has been heated up. When either method is used, the water should be heated until it is at or about the boiling temperature. The required maximum testing pressure of 25 per cent. above the working steam pressure is then applied by again connecting the force pump to the boiler.

It is customary when testing boilers to have two steam gauges placed conveniently so as to permit of easy observation by the officials conducting the test.

Two gauges also serve as a check on each other and prevent any serious consequences due to incorrect registering of pressure. Under no circumstances should the test pressure be such as to strain unduly any part of the boiler.

85. In addition to the hydrostatic test, the flat surfaces of the firebox are inspected by what is called a hammer test. This consists of tapping the sheets and stays with a light hammer and judging from the sound produced whether the parts are defective or not. The hammer test is especially adapted for testing the long staybolts and crown stays in a firebox, as it is next to impossible to test these by any other method. Flexible staybolts are tested by removing the caps and tapping the bolts with a light hammer.

The inspection by a hammer test requires the services of an experienced and competent inspector or boilermaker. The Federal regulations require that rigid staybolts and flexible staybolts without caps shall be tested once each month.

86. Factor of Safety.—No boiler is operated with a pressure at or near its calculated bursting pressure, but at a pressure called its safe working pressure. The ratio between the calculated bursting pressure and the safe working pressure is called the *factor of safety*. For example, if the calculated bursting pressure that will disrupt a boiler is 800 pounds per square inch, and the working pressure is 200 pounds per square inch, the factor of safety is 800 divided by 200, or 4. The Federal regulations provide that, effective January 1, 1923, the lowest factor of safety for locomotive boilers shall be 4.

POOR-STEAMING LOCOMOTIVES

87. Causes of Poor Steaming.—A poor-steaming locomotive is one in which the boiler will not generate steam fast enough to meet the requirements of service. With such a locomotive it is very difficult to maintain full boiler pressure except under very favorable conditions of operation.

The modern locomotive is designed and proportioned in accordance with experience and observation, and therefore when an engine steams badly, the trouble should not be too hastily charged to faulty designing. The fault may occasionally be in the design, such as cylinders too large for the amount of heating surface, insufficient water spaces, or the diaphragm too close to the tube-sheet, but it is far more likely to be due to other causes over which the engineer has control. Aside from faulty design, there are three general causes that will make a locomotive steam poorly: (1) Improper or insufficient draft; (2) the heat of the fire not being fully utilized; and (3) poor management on the part of those in the cab.

88. Insufficient Draft.—Insufficient draft may be due either to some obstruction in the firebox, tubes, smokebox, or stack, or to insufficient vacuum being formed in the smokebox by the exhaust steam, this meaning that the difference between the atmospheric pressure and the smokebox pressure is not enough to create the proper draft, or to the fact that, while a sufficient vacuum may be formed by the exhaust steam, its effect on the fire is partly destroyed through some defect in the draft apparatus. The obstruction to the draft may perhaps be in the grates, which may be fitted so close as to prevent the admission of a sufficient quantity of air through the fire.

Some of the tubes may be stopped up, due to careless firing or to poor regulating of the draft appliances. If the draft is weak, ashes and cinders will gradually accumulate in the tubes until finally they become stopped up.

89. If the draft is too strong, large cinders will be drawn into the tubes and flues and produce the same effect as when the draft is too weak. Plugged tubes and flues reduce the

heating surface of the boiler and hence its steam-generating capacity. If the tubes and flues are obstructed at the firebox end by honeycomb, the effect will be the same as if the tubes were plugged.

If the firebox is reasonably clean and there are no ashes or cinders in the tubes and flues, the cause of the poor draft may be in the smokebox. The diaphragm or deflector plates may be too close to the tube-sheet, the diaphragm apron or damper may be too low, the netting may be clogged or the smokebox may be filled up with cinders. The foregoing shows that as little obstruction as possible should be imposed on the flow of the gases to the atmosphere, other than what is necessary to produce a uniformity of draft over the whole heating surface.

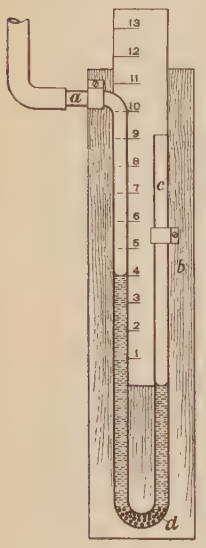

FIG. 23

90. Measurement of Draft.—The draft is measured by a draft gauge, a view of which is shown in Fig. 23. This device consists of a U-shaped tube containing water, and having a sliding scale graduated in inches, the whole being suitably mounted on a part *b*. The upper end of the leg *a* of the tube is connected to and opens into the smokebox so that the water within the tube is subject to smokebox pressure, and the end of the other leg *c* is open and exposed to atmospheric pressure. The water in both legs will stand at the same level when the pressures in the legs are equal, as when the locomotive is not working. With the locomotive working, the draft reduces the pressure in the smokebox and on the water in leg *a*, and the greater pressure of the atmosphere acting on the water in leg *c* raises the water in leg *a*.

The draft is measured in inches of water as follows: The sliding scale is moved so that the zero reading is in line with the lower water level, as shown, and the figure which then comes opposite to the higher water level is noted, which in

Fig. 23 is 4. With this reading, the draft would be said to be equal to 4 inches of water, this meaning that the difference between the pressure of the atmosphere and the pressure in the smokebox is sufficient to maintain a column of water 4 inches high. A pressure equal to 1 inch of water in a draft gauge is equal to about $\frac{1}{2}$ ounce, so that 4 inches would be equal to about 2 ounces of pressure per square inch.

In locomotive practice the draft varies between 4 and 10 inches of water. The shot *d* in the bottom of the tube prevent a too rapid movement of the water due to change in pressure.

91. Insufficient Vacuum.—The firebox and the tubes may be clean and the smokebox appliances may be properly adjusted, but still the engine may not steam. The cause may then be due to insufficient vacuum being formed in the smokebox. Insufficient vacuum may be due to any of the following causes: The nozzle may be so large that the exhaust steam will pass through the smokebox at a very low velocity; the exhaust pipe may be set out of line with the center of the stack, thus throwing the jet more on one side of the stack than the other, or part of the jet may strike the inside of the smokebox proper, or the petticoat pipe may be so set as to have the same effect on the exhaust jet as if the exhaust pipe were out of line.

The principal causes, however, of an insufficient vacuum in the smokebox are air leaks in the smokebox or steam leaks from the steam pipes and superheater units into the smokebox. If the door of the smokebox is improperly set and air can enter through the joints, the action of the exhaust jet will draw air through the openings and less will come through the fire.

92. In superheated locomotives with outside steam pipes, the hole in the smokebox is generally made large enough to permit the flange *e*, Fig. 24, on the steam pipe next to the valve chamber to pass through easily. As the flange is considerably larger than the pipe proper, the hole is much larger than the pipe and should be carefully covered to make it tight. Steam leaking from the pipes has the same effect on the vacuum as air leaks, as both fill the space that should be filled by the products of combustion from the firebox.

Insufficient vacuum is indicated by what is known as a *red fire* or by soot forming on the fire-door.

93. Fig. 24 shows a type of steam-pipe casing that is used to make an air-tight joint at the smokebox where outside steam pipes are employed.

The casing consists of a jacket *a*, a gland *b*, and an outside jacket *c*. The lower end of the steam pipe *d* is flanged at *e* so that it can be bolted to the valve chamber. The jacket *a* is made in two pieces so that it can be placed around the

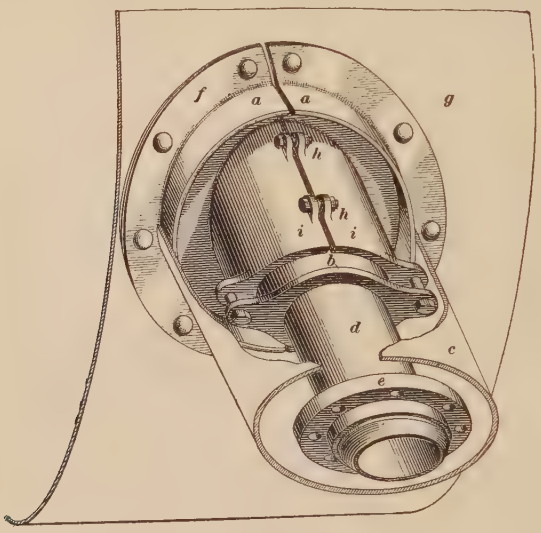

FIG. 24

steam pipe *d*. The part *f* of the jacket is flanged and is here shown riveted, although it is usually bolted, to the smokebox *g*, and thereby closes the opening in the smokebox around the steam pipe. The two parts of the jacket around the steam pipe are held together by the nuts and bolts *h*. In order to prevent air from entering the smokebox between the part *i* of the jacket and the steam pipe *d*, the space between these parts is packed with rope asbestos, which is held in place by the gland *b*. The outside jacket *c* provides a covering for the insulation that is placed around the steam pipe *d* to prevent the steam from

being cooled. This outside jacket is made of thin sheet metal or Russia iron and is held together by means of bolts at the back. It fits snugly at the top to the jacket *a*, and at the bottom to the top of the valve chamber.

94. Poor Circulation. —Another cause of a poor-steaming engine is a poor circulation of water, or a dirty boiler with the heating surfaces covered with mud and scale. To promote circulation, the feed-water should enter the boiler near the front tube-sheet so that it can work along to the tubes and the flues to the hot surfaces and rise with the steam.

95. Poor Management.—Another cause of a poor-steaming engine is poor management and lack of cooperation on the part of those in the cab. To obtain the best results, the firing and feeding should be carried on according to approved methods. The use of the injector has a very important effect on the steaming of a locomotive. The best fireman cannot maintain a good head of steam if the engineer insists on flooding the boiler. Neither can the required amount of steam be produced if the engineer works the engine at a long cut-off when a shorter one obtains the same if not better results.

HAND FIRING OF LOCOMOTIVES

FIRING COALS OF THE EASTERN STATES

INTRODUCTION

1. Purpose of the Instruction.—Before a man can be an efficient locomotive fireman, there are many things that he must learn. Some men acquire this knowledge during years of firing service, learning from the hard knocks of experience. Others learn through the quicker and easier method of studying the experience of others as set forth in written instructions. The purpose of this instruction is to furnish practical information to locomotive firemen on all necessary subjects pertaining to the firing of the coals of the Eastern States.

2. Importance of a Knowledge of Coal.—One of the first essentials of an efficient fireman is a knowledge of the different kinds of coal. There are more than fifty varieties of coal in the country and every variety is burned in locomotives. Some of these coals are good steam coals, others are only fairly good, and still others are burned in a locomotive firebox only with the greatest difficulty.

As there are so many grades and varieties of coals, it is easy to understand that the methods of firing employed must be suitable to the grade and variety of the coal used, and the fireman must know what method to employ in each case. Furthermore, the ash-pan, grates, firebox, and draft adjustment must be suitable to the coal being burned, and the fireman should know whether the conditions are right. If an engine is designed to

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burn a certain type and grade of coal, better results will be obtained with that grade than with either a better or a poorer grade. For that reason, where conditions will permit, each coaling station should be continuously supplied with the same grade and type of coal, and the locomotives should be properly equipped and drafted to burn it. Under conditions where many grades of coal are supplied and must be burned in the same firebox, the fireman must learn to fire the different grades so as to obtain the best results with each.

COALS AND THEIR COMBUSTION

3. A study of the coals of the Eastern States shows that they consist of high-rank bituminous, semibituminous, semianthracite, and anthracite. Bituminous coal may be either a coking coal or a free-burning coal.

Coals that coke vary widely in coking properties. Those with the greatest tendency to coke swell up in burning, become pasty, and fuse into a mass of porous coke. This forms a protective covering over the surface of the fire, restricts the draft through the fire, and so cuts down the steaming capacity of the boiler. To offset this, the coke covering must be broken up from time to time with a slash bar, so that air can pass through the fire readily.

Coals that do not have a strong tendency to coke may become partly pasty but retain their form to a considerable extent unless disturbed. With some coals, if the rake is used on the fire, or, in some cases, if the grates are shaken roughly, the coal will run together and fuse into a porous coke that will cause considerable trouble.

Some coals have no tendency to coke. Such coals do not swell, soften, or fuse, but burn away gradually, becoming smaller and smaller until only the ash finally remains. Such coals are called free-burning to distinguish them from the coking coals. They may be raked freely without causing trouble unless in the process some of the ash is raised up into the hot zone of the fire, where it will melt and clinker.

4. Gas Coals.—In locomotive service, the bituminous coals are commonly known as gas coals, owing to the fact that about one-third of the weight of the coal is converted into gas during the process of burning. This gas is very hard to burn economically. If the firebox and draft appliances are not designed and adjusted to burn it, or if the firing is not done properly, a great waste of fuel will occur and clouds of black smoke may be produced. The other two-thirds of the coal consists of fixed carbon. This is the part that forms coke, which burns without smoke, like the coke of commerce. It burns at a bright red heat, without flame, and remains incandescent as long as burning continues, the heat produced by the combustion being sufficient to maintain incandescence. To obtain smokeless combustion, therefore, the gaseous part of the coal must be burned completely. It is comparatively easy to burn smokelessly any coal in which the gaseous matter does not exceed one-fifth of the weight of the coal.

5. Best Steam Coals.—Coals containing about one-fifth gaseous content and four-fifths fixed carbon give the best results for steam purposes. Those with a greater gas content have a lower heating value and give trouble from smoke, unless conditions for smokeless combustion are just right. Those with less than one-fifth gaseous content also have a smaller heating value, and are harder to ignite; but they burn without smoke even under rather unfavorable conditions.

6. Gases in the Coal.—The gases in the coal are driven off while the coal is being heated to red heat and are burned before the fixed carbon begins to burn, this action requiring from one-half minute to two minutes, depending on the rate of burning and the consequent firebox temperature. Where bituminous coal from the Eastern States is being burned, this means that one-third the weight of coal that is put in at a fire is burned within two minutes after firing. If a heavy fire of, say, nine scoops holding 15 pounds each were to be put in at a fire $(9\times15)\div3=45$ pounds of gaseous matter would be burned within two minutes, which is $22\frac{1}{2}$ pounds per minute. As about 300 cubic feet of air is required to burn a pound of the

gas, $300 \times 22\frac{1}{2} = 6{,}750$ cubic feet of air, or the capacity of about three ordinary box cars, would have to pass through the firebox per minute merely to burn the gas of the nine scoops of coal. The coke of the coal burns in the fire bed with the air that comes through the fire, but the gas burns in the firebox space above the fire bed, and the air necessary to burn it must be supplied at that point. If the air is not supplied the gases cannot burn, but will simply be distilled from the coal by the heat of the fire and pass out of the stack unburned.

7. Coal Loss Through Unburned Gases.—When burning the high-volatile coals of the Eastern States, a very serious loss of fuel may occur through the escape of unburned gases unless the fireman knows how to prevent it. In burning, 1 pound of fixed carbon evolves 14,650 heat units, whereas 1 pound of the coal gases evolves 23,500 heat units. In a high-volatile, high-grade coal composed of two-thirds fixed carbon and one-third gaseous content, the two-thirds pound of fixed carbon would evolve 9,766 heat units and the one-third pound of gases would evolve 9,669 heat units. In other words, the one-third pound of the gases actually represents one-half of the heat value of the pound of coal. With such a coal, if a fireman allows his fire to get into a condition such that only half of the gases escape unburned, he would have the same waste of coal as if he burned all the gases but threw every fourth shovel of coal off the tender. With a high-volatile coal, it is an easy matter to waste a large quantity of fuel through unburned gases if there is insufficient draft or firebox volume, or if the fire is allowed to become dirty or too thick, or holes or banks are allowed to form. A much larger firebox volume is needed to burn a high-volatile coal without smoke than to burn a low-volatile or smokeless coal, and much more skilful manipulation of the fire is necessary.

8. Smoke-Forming Constituents of Coal.—In the manufacture of illuminating gas, a high-volatile coking coal is placed in an air-tight retort and heated until all the volatile is driven off. This process results in four products: coke, gas, tar, and sulphate of ammonia.

The coke is the fixed carbon and ash of the coal, which are left after the volatile is driven off through the heating of the coal. It amounts to from 65 to 75 per cent. of the weight of the coal, which is 1,300 to 1,500 pounds per ton of 2,000 pounds.

The gas obtained averages about 9,000 to 10,000 cubic feet per ton of coal coked.

The tar averages from 4 to 6.5 per cent., which is from 80 to 130 pounds per ton of coal.

From a ton of coal about 20 to 25 gallons of watery liquor is obtained, from which 1 to 1.5 per cent. (20 to 30 pounds) of sulphate of ammonia is obtained.

9. High-volatile coal in burning separates into four parts—coke, gas, tar, and ammonia liquor—the first three of which must be taken into account by the locomotive fireman. The fixed carbon, which may be coke, forms the fire bed, and there must always be a sufficient depth of it carried to prevent the draft from disrupting the fire bed and forming holes. Otherwise, the fixed carbon does not cause serious trouble, as it does not form smoke in burning, but lies quietly on the grates until it is completely consumed. If the fixed carbon cakes over the bed of the fire and forms a crust that prevents the free passage of air through the fire bed, it must be broken up periodically with the slash bar so as to allow a free passage for the air, otherwise it will be impossible to keep up the steam pressure. In breaking this crust, care must be taken not to raise the ash up into the hot zone of the fire, as it will fuse and form a clinker that will produce trouble. The fire bed must not be penetrated with the slash bar farther than is necessary to break the crust.

10. Quantity of Gas Given Off.—The quantity of gas given off by a coal may vary from 5,000 cubic feet per ton in a low-volatile coal to 10,000 cubic feet per ton in a high-volatile coal. If the firebox volume, the air passages through the ash-pan and the grates, and the amount of draft are sufficient, and the draft is properly adjusted for burning the proportion of gas produced by the coal, there should be no difficulty in burning the gaseous portion of the coal smokelessly, provided the fire-

box is equipped with a brick arch. If smoke occurs at heavy rates of firing, it may be reduced by leaving the fire-door on the latch for a short period after each fire, so as to admit above the fire the air necessary to burn the gases while they are driven off in heaviest volume.

11. Tar Distilled From the Coal.—The tar distilled from the coal consists of about 50 per cent. of pitch and 50 per cent. of hydrocarbon oils and liquid paraffins. A coal rich in tarry vapors is a most persistent smoke maker, as the tar constitutes the worst smoke-producing constituent of the coal. The power of tarry vapors to make a dense black smoke will be readily understood if a small piece of tar is thrown on a fire and the quantity and color of the vapor that arises from it are noted. If the firebox temperature is high enough, any tar that escapes burning is decomposed into soot and fixed gases. The soot makes dense clouds of smoke, while the gases that escape unburned are a source of fuel waste.

12. Tendency of Coal to Produce Smoke.—The tendency of a coal to produce smoke depends on both the relative total quantity of volatile matter and on the temperature at which the smoke-producing part of the volatile matter is driven off. For example, Illinois and West Virginia Pocahontas coal contain practically the same amount of smoke-producing volatile matter. The Illinois coal gives off the major portion of its smoke-producing volatile at a low temperature (between 900° F. and 1,100° F.), and for that reason is a very hard coal to burn without smoke; the Pocahontas coal gives off the major portion of its smoke-producing volatile between 1,200° F. and 1,500° F., a temperature at which it is burned smokelessly with but little effort. Connellsville, Pennsylvania, coal gives off its major portion of smoke-producing volatile between 1,100° F. and 1,500° F., but as it contains a much greater proportion of smoke-forming volatile it must be burned with great care to prevent dense black smoke.

13. Rate of Distillation of Volatile.—Experiments have shown that the quantity and quality of the volatile distilled from a coal depends on the rate at which the coal is heated and

the volatile driven off. With a slow rate of heating, the volatile is smaller in quantity and has a higher percentage of gas and a smaller amount of tarry matter. With a rapid rate of heating, a larger amount of volatile is obtained and a much larger proportion of this is in the form of tarry vapors and of hydrocarbon gases, which are hard to burn without smoke. For that reason, it is much harder to burn a coal without smoke at high rates of combustion than at low rates of combustion if the coal contains heavy smoke-producing volatile matter. Such a coal must have ample draft and ample air spaces in ash-pan and grates, the fire must be clean and as light as can be carried for the work the engine is doing, and there must be no leaks in the firebox or at the front end. At high rates of burning, smokeless combustion will be helped greatly by swinging the fire-door or leaving it on the latch for a short time after each fire. The fire-door must be swung shut after each scoop, so as to maintain a sufficiently high firebox temperature to insure smokeless combustion.

14. Smokeless Coals.—Coals, such as the semianthracite and semibituminous coals, that have not more than 20 per cent. of volatile matter are usually known as smokeless coals, because they can be burned at a much higher rate than the bituminous coals without producing black smoke. The reason for this is twofold: first, they have a smaller amount of volatile matter, and second, most of the tarry matter has been driven off through the longer period of pressure to which they were subjected. On the other hand, they are more friable and are not so well suited for transportation and repeated handling as the bituminous coals, especially the central bituminous coals of Illinois, etc., so they carry a higher percentage of slack coal, which must be taken care of by the fireman in order to avoid a large fuel loss.

15. Slack Coal.—Probably the worst fuel loss that a locomotive fireman has to contend with is that which occurs through the escape of unburned fine coal. Where the percentage of fine slack coal is very high, this loss may amount to one-quarter or even one-third of the coal fired. As a scoop of

coal is being fired, the draft picks up the fine coal and shoots it through the tubes and out of the stack, in many cases even before it has been heated sufficiently to drive off the volatile gases. The harder the engine is working the stronger will be the exhaust and draft and the greater will be the fine-coal loss. That is one reason why the fuel record of a man in heavy freight service suffers when compared with the record of a man in light freight service of moderate schedule speed. Not only is the fine coal wasted, but the sparks and live cinders thrown out along the right of way are responsible for many fires during dry seasons of the year.

16. Reducing Slack-Coal Loss.—The best method of reducing the loss through unburned fine coal is to wet the coal until the fine particles stick together while being fired. This can be done only by thoroughly drenching the coal at least a half hour before leaving time, so that the surplus water will have time to drain off. A *light* wetting will not prevent the loss of the fine coal and will add to the fuel loss, because the water must be evaporated and heated to the stack temperature at the expense of the heat of the firebox. In case the coal is sprinkled to keep down the dust in the cab, only just enough water to serve the purpose should be used, to reduce the loss through evaporation of the water.

17. Ash From Coal.—The analyses of coals of the Eastern States show that the ash may vary from 2 to 15 per cent. of the weight of coal. A fireman firing a coal with 15 per cent. of ash would fire 300 pounds of ash and 1,700 pounds of coal for each ton of coal used; with a coal having only 2 per cent. of ash he would fire only 40 pounds of ash and 1,960 pounds of coal. Furthermore, the extra 260 pounds of ash in the high-ash coal would clog the fire and probably clinker, and would interfere greatly with the proper burning of the coal. It certainly would cut down both the efficiency and the capacity of the firebox, and would tend greatly to produce smoke.

18. Foreign Impurities.—From the fireman's viewpoint the ash of a coal includes not only the inherent ash which is a definite part of the composition of the coal but also the

impurities that become mixed with the coal during the process of mining and in transportation and after handling. The impurities foreign to the coal are the real trouble-makers. The inherent ash of a coal will not cause trouble from clinker if the fire is properly manipulated and the ash is not raised up into the hot zone of the fire. The foreign impurities, on the other hand, are sure to cause trouble.

The foreign impurities may consist of: iron pyrite, which occurs in some beds of coal in balls, bands, and lenses and in other beds in veinlets or as small particles and usually is a trouble-maker on account of the tendency of its iron to form clinker; slate, shale, and sandstone from the roof of the mine; slate, shale, and sulphur balls sandwiched in between the coal strata; clay from the floor of the mine; and pieces of iron, rock, and earth that are picked up en route or in the subsequent handling of the coal.

19. The foreign impurities are very apt to give trouble through clinkering. If they do not fuse they settle down onto the grate and as the run proceeds gradually form a screen on top of the grate that shuts off a large part of the grate air space and so restricts combustion. If the fireman does not know the cause of the trouble he will probably fire more heavily than usual, with the result that the thickness of the fire bed will be increased and the steam production decreased.

A great deal of worry and hard labor will be avoided if the fireman will watch every shovel of coal fired for pieces of rock, slate, and other impurities. These should be picked out of the coal and placed in a pile at one side near the gangway where they can be thrown off at some point where there is no danger of hurting persons who might possibly be along the right of way.

20. Hard Clinker.—The formation of hard clinker in a locomotive firebox is one of the chief causes of a fireman's troubles. Where clinker does not form, it is a comparatively easy matter to carry a light, level, clean fire that is easy on the coal pile and makes steam freely. When clinkers form, the fire becomes dirty, grows thick, burns unevenly, smokes, and steam

pressure is maintained with the greatest of difficulty. Since the hard clinker, which is the form ordinarily met with, is formed generally by the melting of some foreign impurity in the coal, the way to avoid the clinker is to watch the coal for impurities and pick them out before firing the coal. The work required to do this is as nothing compared to the work and worry caused by throwing the impurities on the fire with the coal.

Hard clinker is sometimes formed by inserting the slash bar too deeply in the fire and raising some of the ash into the hot zone of the fire, where it melts and in cooling cements a lot of coal and ash together into a big clinker. The way to avoid this is to use the slash bar as little as possible, and then with care.

The appearance of the fire indicates when a clinker is forming. When a spot in the fire begins to grow darker in color than the rest of the fire and it is not due to a bank, it indicates that the air is restricted through that spot, probably due to the formation of a clinker. As soon as this is noticed the clinker should be broken up by a careful operation of the grates. The time to do this is when the clinker first forms. If it cannot be broken up by shaking the grates, it should be raised to the surface of the fire and removed at the first opportunity.

21. Soft Clinker.—Soft clinker is a slag formed by the chemical combination of the constituents of the ash at firebox temperature. To bring about this chemical combination, sufficient heat must be supplied to cause fusion. When a soft clinker first forms the appearance of the fire is the same as if a hard clinker had formed, but the soft clinker grows steadily in size until finally it spreads over the whole grate area. Inspection will show that the clinker is in a fluid condition underneath the crust. The fluid portion penetrates through the lower ash and often hangs like icicles from the grate bars.

Fortunately all ash does not contain the right constituents for combining chemically to form a slag at firebox temperatures. Also, the temperature of fusion usually is higher than the temperature to which the ash is subjected. It should always be borne in mind, however, that the temperature may be near slagging temperature and anything that may increase it only

slightly may cause the ash to start slagging, and once this is started, it is practically impossible to stop it. The only way to remedy the trouble is to pull the fire, clean the firebox *and the grate,* and start a new fire.

22. Anything that increases the ash-pan temperature has a tendency to cause the formation of soft clinker, and anything that tends to reduce that temperature tends to prevent the formation of clinker. Therefore, as a precautionary measure against the formation of clinker, the ash-pan, which should have ample air openings, should be kept clean and after the grates are shaken, when weather conditions will permit, the hot ashes should be cooled by spray piped from the injector overflow pipes. The grates should not be shaken hard enough to shake burning coal into the ash-pan.

23. Mixing Coals.—Many coals may be mixed and burned without causing trouble from clinker. On the other hand, two coals, neither of which clinkers in burning, may cause considerable trouble from clinker if mixed and burned together, or if burned in the wrong order. For example, if anthracite or semianthracite is fired on a fire bed of bituminous coal, the result is almost sure to be disastrous, whereas bituminous coal can be fired on a fire bed of anthracite without the least trouble. It is well, therefore, for a fireman to know whether the coals at the two ends of a division can be burned together without causing trouble.

CONDITIONS FOR ECONOMICAL COMBUSTION

24. Draft of Locomotives.—It is important that an engine have the proper draft for burning coal economically at the rate necessary to supply the maximum amount of steam. If the draft is not sufficient, the engine will not steam, especially when working hard. If the draft is not distributed evenly, the fire will not burn evenly. When the action of the draft on the fire is not what it should be, the fireman should report it, being careful to tell exactly what is wrong. It should be borne in mind that while the action of the draft on the

fire is not right, the trouble may not be due to wrong adjustment of the draft appliances, so no readjustment should be made until the actual cause of the trouble is located. If the fire indicates too little draft the draft appliances may be properly adjusted to produce the necessary draft, but steam or air leaks into the front end, or an obstruction in the ash-pan, grates, tubes, front end, or the netting may be reducing the amount of air flowing through the fire. Of course, the draft can be increased by reducing the size of the nozzle or by bridging the nozzle, but that will simply increase the waste of fuel through increasing the back pressure in the cylinders. The proper procedure is to find the cause and remedy that without touching the draft appliances unless they are found to be at fault. The ash-pan openings may be partly closed or the pan may be too full of ashes. A large number of air openings in the grate may be filled up. Often 60 per cent. of the openings have been found entirely closed. A large number of the tubes may be plugged up or the netting may be choked. The fireman should determine wherein the trouble lies so that he can turn in a correct report.

25. Draft Restrictions.—If a number of the air spaces in the grate are stopped up the fire will burn both poorly and unevenly on account of a lack of air. If the ash-pan opening on one side becomes partly closed up and the total amount of ash-pan air opening is small, the fire will burn poorly on the side on which the ash-pan opening is partly closed.

A fireman should insist that the real cause of any trouble be located *before any change is made in the draft appliances*. Of course, the draft can be regulated to offset the effect of leaks or other defects, but this means burning more coal to keep up the steam supply and additional work for the fireman. On the other hand, if the real cause of the trouble is located and remedied, the extra coal and work can be saved.

26. Failure of Engine to Steam.—Failure of an engine to steam, after being fired in accordance with the best practice, can generally be laid to a condition or set of conditions that decrease the draft or flow of air through the fire.

This may be due to conditions over which the fireman may or may not have control. The dampers or ash-pan netting may not be open, or the ash-pan may be full of ashes. Conditions over which he has no control are leaky steam pipes or superheater units, wash-out plug leaking in front end, blocked flues or netting, air leaks into smokebox, exhaust nozzle loose and leaking, and exhaust-nozzle tip of the wrong size or out of line with the stack. There may not be sufficient opening through the grates, or bricks may have fallen out of the brick arch.

The symptom of a reduced draft through the fire is difficulty experienced in getting the fire to burn white, as it will have a more or less dull color. Leaking tubes apparently reduce the draft out of all proportion to the extent of the leak. This is due to the fact that when water is heated to form steam, it increases in volume about eighteen hundred times. The steam generated from a small leak in the tube-sheet then has an appreciable effect in decreasing the draft through the fire.

27. Scale and Soot.—The effect of scale and soot on the steaming qualities of an engine is very marked. The loss in heat transmission due to ordinary scale varying in thickness up to $\frac{1}{8}$ inch may amount to 10 or 12 per cent. This means that out of every ton of coal fired from 200 to 250 pounds is practically wasted. In other words, in doing work that ordinarily would require the fireman to fire nine tons of coal with tubes clean of scale, the scale would make him fire ten tons, and he would have a much harder struggle to maintain steam pressure. On some roads today it is the practice when a locomotive has been out of the shop for six or eight months to either reduce the nozzle tip or to bridge it in order to offset the bad effects of scale and leaks. A much better practice is to treat the water and so avoid the formation of scale.

Soot is formed whenever coal is burned, but the better the combustion, the less soot will be formed. When the condition of the fire or careless firing causes smoke, clouds of soot are formed that coats the heating surfaces and seriously retards the transfer of heat to the water. Soot is said to be five times as good a non-conductor of heat as asbestos. Of course, the

scouring action of slack coal passing through the tubes tends in a measure to clean them of soot, but even at the best there is a considerable fuel loss through soot. The fireman should watch for soot and should see that the tubes are bored out and cleaned frequently, thereby saving himself much unnecessary labor.

28. Waste at Pop Valve.—With a free-steaming engine, it is often difficult to prevent a large waste of steam at the pop valve. For every minute the pop is blowing, 15 pounds of coal is wasted. If during a run the aggregate time of blowing equals 90 minutes, the coal wasted will amount to $90 \times 15 = 1{,}350$ pounds. The pop wastes a scoop of coal each minute, so that every time it "lets go" the fireman must bend his back and put in a scoop of coal. This aggregates ninety scoops for the 90 minutes the pop was blowing, so the engineman can save the fireman much labor by being careful to prevent the pop from blowing.

If the fireman knows the run, it should be a comparatively easy thing for him to plan each fire far enough ahead so that when a regular stop occurs the pop can readily be prevented from opening. In local passenger service, when stops are many and short and stations close together, there is added difficulty in preventing pop waste. Just before closing the throttle the engineer should put on the injector and the fireman should crack the blower. This should prevent the pop from opening; but if indications are that it will not, the fire-door should be put on the latch or swung open and shut just enough times to prevent the pop from opening. While the engine is using steam, the fire-door should never be left wide open to prevent the pop from blowing or to cause the pop to cease blowing, as the large volume of cold air that would flow in a continuous stream through the firebox and tubes would cause tube leakage.

29. Cooperation of Engineer and Fireman.—The engineer and fireman must work in harmony with each other if good results are to be obtained. When pulling out of stations, the injector should not be started until the fireman has the fire in good condition, and the steam pressure is increasing. Otherwise the fire will have to be crowded to hold up the steam pres-

sure. When approaching shutting-off points, the fire can be allowed to burn down somewhat, and the water level at this time should not be so high as to prevent the injector from being used to keep the engine from popping. The engine should not be run first with a light throttle and then with a heavy throttle, nor should the cut-off be changed frequently, as working the throttle and reverse lever in this way makes it impossible for a fireman to carry a steady fire and an even steam pressure. The position of the throttle and lever should, as far as possible, be changed only when a change in grade makes it necessary.

DETAILS OF FIRING

30. Preparing Fire for Start.—It is of the greatest importance to have a good fire with which to start the trip. If the fire is not put in shape before starting, it will give the fireman all kinds of trouble. For that reason he should get around in sufficient time to have his fire in perfect shape before leaving time, as he thereby will save himself much worry and hard labor during the run.

On arriving at his engine he should see whether the fire has been well cleaned. If it has not, he should knock out any clinker or ash that remains. Next, he should close the fire-door and put on the blower long enough to start the fire burning brightly so that he can detect any dead spots in it. Sometimes the fire cleaners in spreading the live coals after cleaning the fire do not entirely cover the grates and fire green coal on the bare spots. With a coal that ignites freely this will not matter so much, as the green coal will gradually ignite and the fire will spread over the dead spot. However, if there is a dead spot with the low-volatile, harder-to-ignite coals like the semi-anthracite, it will cause so much trouble that it should be done away with before starting. The green coal should be pulled away from the dead spot, the grate covered with good live coals, the green coal spread over the live coals, and the blower applied just long enough to ignite the green coal thoroughly.

31. Building Up the Fire.—After the fire has been put in good condition all over the grate surface, fresh coal should

be lightly spread over it, and, if necessary, the blower put on very lightly. If there is sufficient time in which to build up the fire without the blower, it should not be used. It has been found by experience that when the blower is used freely in building up a fire, more clinker is formed and the fire is not in as good condition as when it is built up under natural draft. After the fresh coal that was spread over the fire is at a cherry-red heat, begin to build up the fire by spreading fresh coal thinly, first over one half of the firebox, lengthwise, and then over the other half. The idea is to always have one half of the fire at a red heat or better, when fresh coal is put on the other half, so that sufficient heat will be assured to burn the gases as they are driven off from the fresh coal. This method of firing will very materially reduce the amount of smoke produced in building up the fire.

32. The fire should be built up to the required thickness for the service as gradually as time will permit. Each fire should consist of only one, two, or three shovelfuls at a time, each being spread lightly and evenly over half of the firebox surface. A charge of coal that has been put on the fire must not be covered with more fresh coal before it has attained a red heat. Below a fairly bright red heat the first charge has not had its volatile matter driven off, and the second fire will simply retard the distillation and will cause the fire to build up too rapidly with green coal. Then, when the fixed carbon of the coal begins to burn, the hot zone of the fire will be so thick and so hot that clinker will result.

33. It is of the greatest importance to have a good fire covering the entire grate surface before leaving time for the trip. The depth of the fire will depend on the size of the coal, the weight of the train, and whether the start will be on an up grade, a level, or a curve. In other words, if the engine will have to work hard to start the train the depth of the fire at starting time must be greater than if the train is easily started. The coal necessary to keep up the steam pressure and to keep the fire in shape while the train is being started should be thoroughly ignited, and burning brightly before starting.

34. Depth of Fire.—It is important to know the best depth of fire to carry under various conditions. Many firemen do not understand this, and are in the habit of carrying one depth of fire at all times unless the thickness of the fire builds up during the run. This is a mistake that causes the fireman much extra work and worry, besides lowering his standing in the fuel records. For light loads, a light fire should be carried, while a thicker fire should be carried for heavier loads. It should not be thicker, however, than is necessary to withstand

TABLE I
EFFICIENCY OF BOILER AND FIREBOX

Depth of Fire Inches	Amount of Load Carried			
	Half Load Per Cent. Efficiency	Three-Quarters Load Per Cent. Efficiency	Full Load Per Cent. Efficiency	One-Quarter Overload Per Cent. Efficiency
6	73.5	67.5	64.0	60.5
7	68.5	67.0	68.5	62.0
8	65.0	64.0	68.0	63.0
9	63.0	60.5	66.5	62.0
10	62.0	57.0	63.0	58.0

the effects of the exhaust, as that thickness will give the greatest fuel efficiency and the least trouble in burning.

35. Fuel Loss Through Thick Fires.—The effect of the thickness of the fire on the efficiency of a certain boiler and firebox is shown in Table I. These results hold good only for the boiler from which the results were obtained. If a test for another locomotive were to be made, the best depths of fire would very probably be different from those given, *but whatever they were found to be, they would vary in a manner similar to these figures.* The results found in the tests are presented merely to emphasize the fact that a lighter fire will give better results at light loads, whereas a heavier fire must be carried for heavy loads.

From the table it will be seen that in this test a 6-inch fire gave the best results for half and three-quarter loads, but that the efficiency was greatest at half load and dropped away rapidly as the load was increased. The 7-inch fire was not as efficient as the 6-inch fire for half load, but gave best results from three-quarters to full load. The 8-inch fire gave best results between full load and one and one-quarter load. The 9-inch fire did not give as good results as the 8-inch fire, while the 10-inch fire was considerably less efficient.

36. Suppose that the man firing for the test had the habit of always carrying a 10-inch fire. How much extra coal would he have had to fire on that account? For half load he would be wasting 11.5 per cent., or 230 pounds, out of every ton fired. For three-quarters load, he would waste 10.5 per cent., or 210 pounds per ton. At full load he would waste 5.5 per cent., or 110 pounds per ton. At one-quarter overload he would waste 5 per cent., or 100 pounds per ton fired. Burning this extra coal means more work in feeding the fire, and more work in keeping the fire at its best, because the more coal that is burned the more dirty the fire becomes. This extra labor and trouble can be avoided by carrying a depth of fire best suited to the load.

37. Preparation of Coal.—Most of the coal furnished for locomotive service is run of mine. Due to differences in the nature of the coal, in mining methods, methods of preparation, etc., there is a big difference in the make-up of the run of mine from different mines. Run of mine from a district where the coal is soft and friable has a high percentage of slack and a correspondingly low percentage of lump coal. Furthermore, the lumps crumble when exposed to the high temperature of the firebox, so they need not be broken so small as the lumps of the harder varieties. With a soft, friable coal, therefore, the loss of unburned slack must be prevented by thoroughly drenching the coal.

38. Most of the coal from the Eastern States is of the harder varieties, so that it has a lower percentage of slack and a higher percentage of lumps, many of which are too large to

go through the fire-door. Now, fine coal and large lumps cannot be burned together, because the lumps burn slowly and tend to cause banks and clinkers; also, holes form around the lumps. A fireman will save worry and labor by breaking up large lumps to the size of medium-sized apples before shoveling them into the firebox.

39. Method of Firing.—The method of firing best adapted to the economical and smokeless burning of the bituminous coals of the Eastern States is indicated in Fig. 1. This shows that the fire is carried level throughout the grate, except

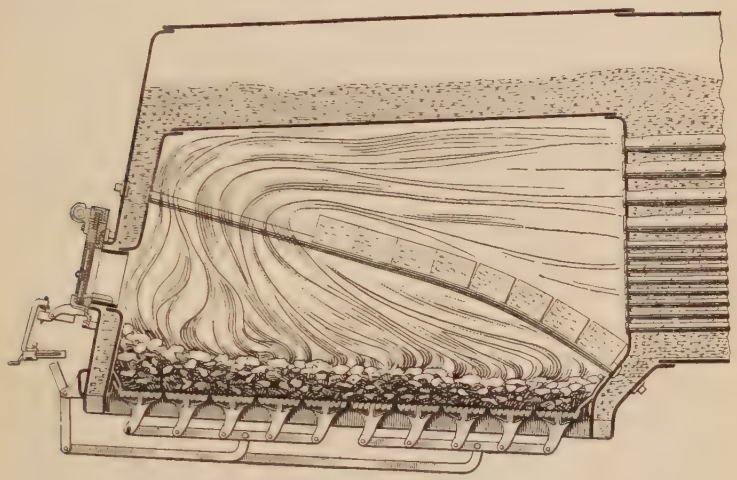

FIG. 1

near the firebox sheets, where a heavier fire is carried to prevent cold air from coming through at those points and causing the sheets to crack and the tubes to leak.

40. The thickness of fire carried should be as light as conditions will permit. A good portion of the fire should be at a white heat, the fire should be free from holes and banks, and the flame should be clear and non-smoky and short enough so as not to reach the tubes.

The thickness of the fire will increase if the ash continues to accumulate on the grate or if coal is fired faster than it is being

burned. The fire should not be allowed to become thicker through the accumulation of ash, because that will surely lead to the troubles that go with a dirty fire. If the grate does not clear itself, it should be shaken very carefully as often as is necessary to prevent an accumulation of ash.

The coal put in at one fire should always be allowed to burn down before another fire is put in that part of the firebox. This is a cardinal principle of firing. If this is done, the fire will not build up in thickness. When the fire is to be built up in anticipation of heavy work, such as climbing a heavy grade, the coal is fired faster than it burns, by shortening the intervals between fires. However, the intervals should not be so short that the coal of one fire does not have time to come to a bright-red heat before it is covered with the next charge of coal.

41. Firebox Temperature.—From the standpoint of both firebox efficiency and smokeless combustion, the temperature of the firebox must be kept high and as nearly constant as possible. If the entire surface of the firebox is covered with green coal at a fire, allowed to burn down and then covered with green coal, the firebox temperature will vary greatly and the steam pressure will vary correspondingly. Such variations mean smoke, leaky tubes, and waste of fuel. The best plan, where the firebox is not too large, is to fire the lengthwise halves of the firebox alternately. In this way, half of the fire can be at a bright-red heat all the time, which will maintain the high constant temperature necessary for good combustion. When the firebox is too large for firing halves, divide it into quarters and fire alternate quarters.

42. Placing the Coal on the Fire.—It is important that the fireman know where and how to place coal on the fire. With engines having sloping fireboxes, care must be taken not to put too much coal under the arch. Both the slope of the firebox and the force of the draft tend to pull the coal ahead, and unless care is taken the fire will be banked up next to the tube-sheet, causing the forward section of the grates to become clinkered over and stuck. Most of the coal should be fired at the back end of the firebox and in the corners and along the

sides. Fire only enough in the front end and in the middle of the firebox to prevent holes from forming.

The coal should be fired with only two or three scoops to the fire. It should be placed on the bright spots and never on the dark spots, as that has a tendency to form banks. The bright spots indicate the places where the fire has most nearly burned through. The intervals between fires should be lengthened or shortened according to the requirements. This procedure will make the fireman's work much lighter, as he will handle less coal and a steady steam pressure will be easily maintained. Also, the coal will be burned with much less smoke than it otherwise would be, as less gas will be liberated to a fire and more time will be allowed for the gas to burn before a new fire is put in.

43. The rate of firing will be in direct proportion to the draft, because the rate at which the fire burns depends on the rate at which the air is passing through the fire bed. Increasing the amount of air passing through the fire makes the coal burn faster; decreasing the amount slows down the rate of combustion. The amount of coal burning at any time must be sufficient to supply the steam necessary to operate the engine properly under the conditions prevailing.

44. Swinging the Fire-Door.—If the engine is not equipped with an automatic fire-door, the fireman should swing the door shut after every shovel of coal, which should be fired in a leisurely manner, so that the door will remain shut for a few seconds after each charge. This method requires a little work but saves the fireman a great deal of labor in the end. For, if he leaves the fire-door open, the cooling effect produced wastes much coal and so increases the amount that must be supplied by the fireman. Furthermore, if this extra coal did not have to be burned, a much cleaner fire would result.

45. Starting the Train.—By leaving time at the terminal station, there should be a good fire burning brightly all over the grates and of a suitable thickness for the work the engine will have to do in starting the train. Under some con-

ditions it may be an advantage to put on the blower for a time just before starting, so as to have a good hot fire. If the train is a heavy one, the new fire may be torn up by the heavy exhausts; so the fire-door should be placed on the latch to reduce the draft above the fire and lessen the tearing effect. When the reverse lever is notched back, a fire should be put in to repair any damage done in starting, and the fire after that should be maintained to suit the work of the engine.

46. When to Put in a Fire.—The student fireman generally experiences difficulty in reading his fire—that is, he is not sure just when a new fire should be put in—the result being that he generally errs on the side of too much coal and crowds his fire, or adds fresh coal before the coal already in the firebox has been sufficiently burned. When this is done, the fire becomes too thick, the passage of air through it is obstructed, the steam pressure falls and there is, depending on the coal used, a tendency for clinkers to form. The time elapsing between firings will depend on the coal, draft, cut-off at which engine is working, etc., and can be determined either by the appearance of the fire or by the time interval between fires. The experienced fireman does not generally regulate his firing so much by the appearance of the fire as by the intervals of time his experience has taught him must elapse between fires under various conditions. In other words, he expects his fire to be in the proper condition for a fresh supply of coal after a certain time. The judgment necessary for a fireman to determine correctly the time between fires can only be acquired by experience, and in the meantime he must be guided to a great extent by the appearance of his fire. When the coal he has fired before his last fire has burned down to a dazzling white heat, this section of the grates is ready for another charge of coal. For example, if his last fire consisted of three scoops of coal on the right side of the firebox, when the left side has burned to a white heat, his next fire should be along that side. When putting in a fire the fireman should practice making a quick survey of the whole firebox and thus ascertain the kind of fire that is being carried.

47. Heavy Firing.—Heavy firing with bituminous coal makes both labor and trouble for the fireman. Some firemen habitually fire from eight to fifteen scoops to a fire when the engine is working hard. That is just the time the most skilful firing should be done; yet by heavy firing the fireman not only wastes a great deal of coal but also reduces his chances of maintaining the necessary steam pressure. A heavy charge lowers the firebox temperature and allows the gases to escape unburned. Cooling the firebox reduces the rate at which steam is generated, thereby reducing the maximum hauling capacity of the engine. On a long grade with a heavy freight, this might mean doubling the hill, whereas a properly fired locomotive would make the grade without doubling.

If a coal composed of one-third volatile matter were to be fired in charges of fifteen scoops, each holding 15 pounds of coal, each scoop would have 5 pounds of gas. The 15 scoops would contain $5 \times 15 = 75$ pounds of gas, and $75 \times 300 = 22{,}500$ cubic feet of air, or the contents of ten box cars, would be required to burn the gases without counting the air necessary for the burning of the fixed carbon. The draft appliances are not adjusted to admit such a supply of air, and so most of the gases escape unburned. The consequence is that the fireman gets no useful results from half the coal he is firing, and just at a time when he should be getting all the heat that the coal is capable of giving. Firing two or three scoops to a fire at frequent intervals would cut his labor in half, maintain a better steam pressure, and greatly reduce the trouble from dirty fires. Furthermore, it would prevent the big fluctuations of temperature that occur with heavy firing, thereby preventing trouble from tube leakage.

48. Firing Poor-Steaming Engines.—Under favorable conditions—that is, when the coal is of fair average quality and the engine is properly drafted—it is a comparatively easy matter to carry a good head of steam if the fireman keeps in mind the correct principles of firing. However, when the conditions are not favorable, due either to the fuel or to the engine, it is only by exercising good judgment that it is possible

to have a successful trip. The fireman should not assume that conditions unfavorable to the free steaming of an engine should cause him to deviate from principles that his experience has taught him produce the best results, as it is only by the application of these principles that the greatest degree of heat can be obtained under any conditions, favorable or otherwise. He should, on the contrary, apply the principles of correct firing to the conditions under which he is working, and, even if the engine is not kept hot, be satisfied that the results derived from their application will be the best obtainable. For example, if steam leaks reduce the vacuum in the smokebox and therefore decrease the draft through the fire, special effort should be made to keep the fire clean and light, so as to facilitate as far as possible the passage of the reduced volume of air entering through the grates to the fire, and thus compensate for the reduction in the draft due to leaks. Care should also be taken under these conditions to fire more lightly than usual, as it is very easy to overcrowd the fire under any conditions that cut down the draft. The tendency, however, when an engine is not steaming freely, is to fire too much coal, which in a great number of cases merely aggravates the trouble. In the case of poor-steaming engines there should be closer cooperation between the engineer and fireman than is usually necessary when conditions are more favorable.

49. Filling Up of Firebox.—Trouble is sometimes experienced by the fire increasing in thickness rapidly even when the grates are shaken frequently. As it is practically impossible in certain classes of service to keep shaking the grates continually, steam failure and detention of the train result. There are two principal causes of filling up the firebox: an excess of ash or foreign matter in the coal, and incomplete burning of the coke. In the first case nothing can be done except to keep the fire as thin as possible by frequent shaking of the grates; but in the latter case the trouble can be avoided by changing the manner in which the coal is being fired.

Some classes of coal burn more slowly than others, and require more time for the gases to distill out, and less smoke is

emitted at the stack. Fresh coal is frequently added before the coal already in the firebox has completely burned, causing the fire to become too heavy. Coal of this nature should be fired as light as possible, erring, if necessary, on the side of too little coal rather than too much, until the correct method of firing is found. An examination of the contents of the ash-pan will show whether the trouble is due to impurities in the coal or too heavy firing, as in the latter case a large amount of unburned coke will be found in the ashes.

50. Shaking the Grates.—How frequently the grates should be shaken depends on the style of grate, the amount of ash in the coal, and the amount of clinker-forming material in the ash. If the grate has the proper air openings for the coal being burned, and the air openings are not plugged up, and if the ash from the coal is fine and does not clinker, it is possible to go from terminal to terminal without shaking the grates. On the other hand, if the air openings are not right, or are filled up, or if the coal is high in ash and clinkers and contains rock and slate that are not picked out before firing, it will be impossible to get along without shaking the grates. The fireman, therefore, must judge as to whether or not it is necessary to shake the grate; however, he should bear in mind that it should never be shaken except when necessary, as fire trouble is apt to result.

If the appearance of the fire indicates that there is a restriction of the air passing through, the grates should be carefully shaken and the shaking should be repeated every time the appearance of the fire indicates the necessity. The time to shake the grates is when the throttle is closed or when the exhaust is very light. The object of shaking is to remove the dead ashes and clinker from the bottom of the fire, and the shaking should stop at the first indication of live fire dropping into the ash-pan, not only to save fuel but to prevent burning out the grates by live fire in the pan.

Care must be taken always to lock the grates in their level position; otherwise, the fingers on one side of the grate bars will project up into the fire and will probably be burned off,

or clinker may get wedged between the fingers of adjacent grate bars and hold them open so that live fire can fall into the ash-pan.

51. Use and Abuse of Blower.—When the blower must be used, turn it on just as lightly as will do the work. If the blower is used too strongly and at the wrong time it will cause damage to the boiler. The most frequent abuse of the blower and the one that does the most damage to the boiler is using it too strongly with the fire-door wide open or when raking or cleaning the fire. In doing this work, the blower

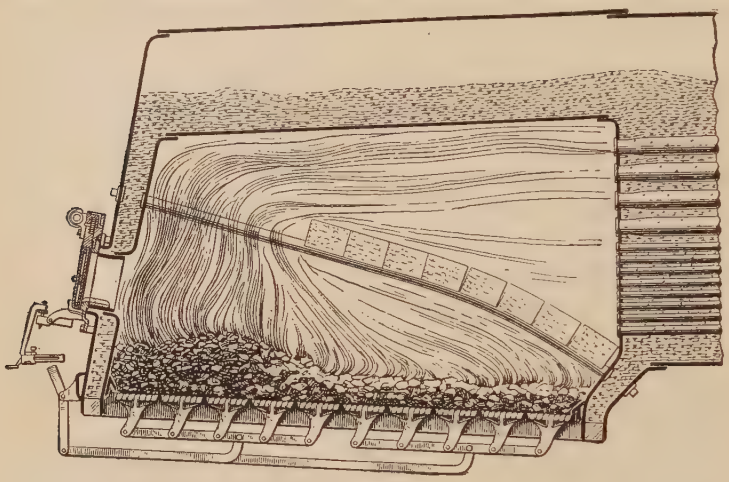

FIG. 2

should be put on only just strong enough to prevent the gases from coming out the fire-door into the fireman's face. Turning the blower on harder than is necessary is pretty sure to cause leaky tubes.

52. Banks in the Fire.—The condition of the fire known as a bank is indicated in Fig. 2, and is brought about by the building up of the fire bed considerably above the level of the fire at one point, due to slow burning at that point. Anything that restricts the draft through the fire at any point in the firebox will cause the thickness of the fire at that point to build up and a bank to form. A clinker on the grates, or firing

one scoop of coal upon another before the coal from the first scoop has had time to get red hot will form a bank. If the draft at one point in the firebox is very light and coal is fired at that point at the same rate as for the rest of the fire where the draft is normal, a bank will build up at the point of weak draft. A bank cuts down the amount of active grate area and makes the distribution of the draft uneven; therefore, it should be removed, if possible, or else coal should be fired around it so as to cause it to burn out. If it is not gotten rid of, it will start a bad clinker.

53. Holes in Fire.—When a hole is allowed to form in a fire, as in Fig. 3, it should be repaired at once. Never fill up a

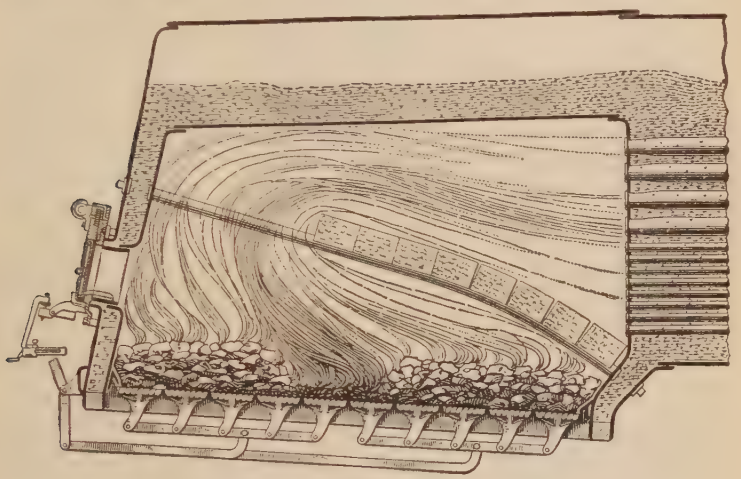

FIG. 3

hole with green coal, as it will either remain a dead spot or develop a clinker, depending on the kind of coal being burned. Fill the hole with live coals by leveling the fire at that point, and then sprinkle fresh coal over the part leveled.

When a hole develops, a large volume of cold air enters the firebox and passes to the tubes in a solid stream that cools the firebox and contracts the tubes and sheets, causing leaks. Also, so much air passes through the hole that the draft through the fire bed is greatly reduced. This still further lowers the rate

of combustion and the firebox temperature, and results finally in cracked sheets and leaky tubes.

54. Clinkers in Fire.—Clinkers cause the worst troubles for the fireman; therefore, he should take all precautions to avoid them. In case they form, the first opportunity must be taken to get rid of them, which may be done by hooking them out, knocking them out, or by raising them to the surface of the fire where they may burn out and crumble. The work of removing a clinker must never be attempted while the engine is working, because in removing it there will be an inrush of cold air, which will cause injury to the firebox sheets and the tubes.

55. Honeycomb.—The cause of honeycomb, or flue-sheet clinker, is not known, although different theories have been advanced. However, it has been found that quite generally a leak in the tubes or the firebox sheets accompanies honeycomb, and that when the leaks are repaired the trouble from honeycomb ceases; also, wetting the coal seems to aid in preventing it. Honeycomb in many cases will be prevented, or at least retarded, by carrying a light, level fire and providing an excess of air in the firebox. When it starts to form it should be knocked off the flue-sheet; otherwise it soon will entirely block the tubes and so cause an engine failure.

56. Station Stops.—When approaching a station, the fireman should have sufficient coal in the firebox to take care of the fire until the start has been made after the stop and the reverse lever has been hooked up. The last fire should be put in long enough before the throttle is closed for the stop, to allow the gases to be distilled and so prevent smoke while at the station and a waste of fuel. When the stop is made, the fire should be sufficient to carry steam pressure until speed is attained in starting. If, through unlooked-for delay or otherwise the fire needs replenishing before this, put the fire in before the train starts. It is a poor practice to put in a fire while the exhaust is heavy, because the open fire-door will let such a large stream of cold air through the firebox and tubes as will cause leakage of the tubes and sheets.

57. Descending Grades.—In approaching a long down grade where the engine will drift with throttle closed, precautions must be observed to keep the pop from blowing. The fire should be burned down as low as possible without dropping the steam pressure. If there is danger that the pop may open after the throttle has been closed, enough coal should be sprinkled over the fire to prevent this. Also, if necessary, the fire-door may be left on the latch or swung back and forth to prevent popping. While the engine is on the descent is a good time to clean the fire if this is necessary.

58. Waiting on Sidings.—When approaching a siding where a long wait is expected, the fire should be burned down as much as possible without lowering the steam pressure. If the fire needs cleaning, this should be done at once so that there will be time in which to build the fire up into shape again before the train has to start. If the fire does not need cleaning, but the injector is working, it should be kept bright until the water level is obtained. Then the fire should be sprinkled over with green coal and if the engine has dampers they should be closed to keep the pop from blowing. If the engine has no dampers, the fire-door should be placed on the latch. The object should be to avoid popping by keeping the fire only high enough to prevent a drop in steam pressure. The fire should never be allowed to get so low as to lose steam pressure, as leaks are apt to develop.

The fireman should begin to prepare his fire in plenty of time before leaving the siding, so that he will have it built up and in condition to withstand the heavy exhausts of starting the train.

59. Cleaning the Fire.—If the fire is always carried as light as is consistent for the work the engine is doing, the fireman will have the least amount of coal to shovel, and the chances are that he will not have to clean the fire while on the road. If he does have to clean it, the work of cleaning it will be very much less than if a thick, heavy fire were carried. Heavy firing, either before or after leaving, increases the formation of clinkers and so reduces the time that a fire can go

without cleaning. By carrying a light fire, therefore, and taking precautions against the formation of clinker, a fireman can save himself the hard, hot work of cleaning the fire during the run.

Where a train is a long time on the road and the fire becomes dirty and clinkered, it should be cleaned at the first opportunity. The fireman will be well repaid for this labor, as he will get better results with less work and coal, and will avoid leaky tubes.

If an opportunity is not presented during the run for thoroughly cleaning the fire, a small amount at a time should be cleaned as conditions permit. In this way it will often be possible to complete the trip, whereas without doing so a stop would have to be made to enable the fire to be cleaned.

60. Cleaning the Ash-Pan.—It is very important that the ashes be not allowed to accumulate in the ash-pan, and that no live fire be shaken into the pan and allowed to burn there. The temperature in the ash-pan rises rapidly as the pan fills with ashes, thereby greatly increasing the tendency of the ash to melt and form a clinker. If fire is allowed to burn in the ash-pan, not only will clinker form on the grates, but also the grates are very apt to be burned out. Some roads pipe the overflow pipes from the injectors into the ash-pans, so that after the grates have been shaken the injector primer can be started and water sent through the overflow pipe to put out any fire that may have been shaken into the pan.

Some roads equip the ash-pan with steam blowers for the purpose of cleaning. In some cases, one pipe in the center is used, while in other cases two pipes are used, one on each side of the center. The steam blower is not only useful in cleaning out the ashes, but also serves to clean the snow and ice from the pan in winter, thereby avoiding delays necessary to melt the snow and ice by means of a fire.

61. Terminal Stop.—On approaching a terminal station, the engineer should see that there is plenty of water in the boiler and that full steam pressure is carried. The fireman should have enough coal burning on the grates so the hostler

will not be required to put in a fresh fire while the engine is in his charge. There should be a good bed of fire left for the fire cleaners, so that the fire can be cleaned properly.

The last fire put in by the fireman should be fired at a distance from the terminal sufficient to enable the gases to be distilled from the coal before the throttle is closed. The fire should be allowed to burn down so that there will be just the right amount of brightly burning coal for the purposes of the hostler when the train arrives at the station.

62. Summary of Firing Instructions.—The following is a brief summary of the instructions on the hand-firing of locomotives as given in the preceding pages; to obtain the results indicated in the following paragraphs it is assumed that the coal used is of fair average quality and does not require any special method of handling when being fired.

The fireman should be at the roundhouse in ample time to prepare his fire properly for the trip. He should ascertain that he has all the necessary tools used in firing on the engine before leaving the roundhouse and should examine the firebox to see if there are any leaks that would be a detriment to the fire or draft and cause engine to fail to steam. The smokebox door should be examined to see that it does not leak and that the nuts holding it closed are screwed up tight. He should ascertain if the grates can be worked, if the fire is free from clinkers, that the ash-pans are clean, and if the slides can be worked. He should also perform any other additional duties prescribed by the rules of the company.

63. The fire should be built up to the required thickness by adding two or three scoops of coal at a time, and putting the blower on lightly. In order to make a solid bed of fire and avoid the formation of clinkers, additional coal should not be added until the coal already in the firebox has been well burned. The final thickness of the fire will depend on conditions, such as the service the engine is in, the intensity of the draft, quality of the coal, etc., but should be sufficient to insure that the starting and pulling out of the train will not injure the fire when the

engine is being worked at long cut-off. When building up the fire, the injector can be put on, if necessary, to prevent the engine from popping.

64. After the train has been started, the coal should be fired at regular intervals, closing the door between scoopfuls. Two or three scoopfuls of coal well scattered should be about the amount necessary to fire at one time. The fireman should aim to keep a level fire by scattering the coal, a bright fire, and a fire of uniform depth by frequent and light shaking of the grates. The fire carried should be as thin as conditions will permit. Banks, holes, and dead places in the fire, especially next the flue sheet, must be avoided. As a general rule, the tendency is for the fire to burn the heaviest in the four corners of the firebox, along the sides, and next the flue sheet. In this event the fire, instead of being level, should be thicker at these points.

65. Fresh coal should not be added until the fire has burned down to a white heat, if the conditions under which the engine is working permit. The steam gauge should be watched closely for indications of improper conditions in the firebox. When the steam pressure begins to fall under apparently favorable conditions, the fireman should examine his fire for banks, holes, or clinkers. The fireman should make a practice of noticing the condition of the fire during the time the door is open when putting in a fire, and should endeavor to carry a mental picture of his fire at all times. Shake the grates as lightly as possible and often enough to keep the fire clear of ashes and of the correct depth to secure the best results for the conditions under which engine is working. The frequency with which the grates should be shaken will depend on the amount of waste material in the fuel, but ashes should not be allowed to accumulate to such an extent as to render a heavy shaking of the grates necessary. The grates should not be opened up too wide at first, but should be partly opened and closed with short quick jerks. This tends to break up clinkers and avoid the possibility of their being caught in the grates and holding them open. With power grate shakers, if the grates are

frequently moved with the limiting lock in position, it will be unnecessary to throw this lock out and open the grates fully.

66. Endeavor to carry as even a steam pressure as possible when the engine is working. This implies a more or less constant firebox temperature and reduces the tendency of the flues to leak. A high temperature can be maintained by keeping the fire bright, clean, and as thin as conditions will permit, the coal being fired light and often, and well scattered, the door being closed after each scoop.

Except when cleaning the fire, use the rake or hook only when necessary to break up the coke. If the coal is broken up small and fired lightly, very little coke will form and excessive use of the rake can be avoided.

To avoid smoke when shutting off for stations, put in the last fire far enough back so that it is burned down. Crack the blower when putting in a fire at stations, and avoid smoke by firing lightly and putting the fire-door on the smoke notch.

The fireman should learn the road over which he is firing and fire according to the grades. He should let the fire burn down for a meeting or passing point if they have to take the siding, and should know where to prepare for the bottom or summit of a hill, and also know how the engineer is going to work the engine at these places.

The deck and gangways of the engine should be kept clean and free from coal not only to prevent loss by falling off, but also to prevent accidents due to stepping on loose coal.

COMBUSTION

CHEMICAL ELEMENTS AND COMPOUNDS

GENERAL DEFINITIONS

67. Every body or mass of matter is either an element, a compound, or a mixture.

A **compound** is a substance formed by the chemical combination of two or more elements, and therefore can always be decomposed into separate substances. Water, for example, is a compound formed by the chemical combination of the gaseous elements, hydrogen and oxygen, and can be decomposed into these elements by passing a current of electricity through it. Any substance that can be decomposed into other substances is called a compound. Examples of compounds are wood, salt, lime, and the resultant gases of combustion.

68. Such substances as cannot be decomposed or broken up into separate substances by any known means are called **elements.** Silver, for example, is an element, and it is made up of but one substance. The innumerable compounds in the world are really made up of various combinations of a comparatively small number of elements. Some of the more common elements are oxygen, hydrogen, nitrogen, carbon, sulphur, iron, tin, lead, copper, zinc, gold, silver, nickel, and mercury. In the study of combustion, however, only the first six of these elements are of interest to the fireman and are the only ones that will be considered here. The elements are generally represented by *symbols,* which usually are the first letter of their names: thus, *O* stands for oxygen; *H,* for hydrogen; *N,* for nitrogen; and *C,* for carbon. A compound is expressed by combining the separate symbols of its elements; such a combination is called its *chemical formula.*

69. Atoms of elements combine to form molecules of elements and of compounds. An **atom** is defined by chemists as the least part of an elementary substance that can enter into or be expelled from a compound. Atoms of the same element are always of equal weight and volume, but they may differ in weight or volume, or in both, from atoms of other elements. They never exist in a separate state, but always combine with one or more atoms to form a molecule.

A **molecule** is the smallest quantity of an element or compound that is capable of a separate existence. It can be divided into its atoms only by a chemical process.

ELEMENTS

70. Oxygen.—Oxygen is one of the principal parts of the air, forming about one-fifth of it; the other four-fifths is nitrogen. These elements are not chemically combined, but are mixed together so that no chemical action is necessary to separate them. Should some element for which oxygen has a greater affinity, or liking for, be introduced into the mixture, the oxygen will leave the nitrogen and make a chemical combination with the other element. A chemical action takes place when oxygen forms a compound with any other element. If this element is a fuel, the chemical action is called combustion.

Combustion, or burning, cannot begin unless oxygen is present, nor can burning continue unless oxygen is available. Oxygen is therefore necessary to start combustion, and also to support it. During combustion, oxygen is the only element in the mixture known as the atmosphere that can be used in burning coal.

71. Hydrogen.—The element called hydrogen is the lightest substance known. It is a colorless, tasteless, odorless gas. In coal it exists in combination with carbon in the form of certain compounds called **hydrocarbons.** When the coal is thrown into the firebox, the heat to which it is subjected causes these hydrocarbon compounds to be driven off in the

form of gases, the chief one being the gas known as **methane,** or **carbureted hydrogen.**

72. Nitrogen.—Four-fifths of the air is nitrogen, which is a tasteless, colorless, odorless gas that will not support life when breathed alone and that will not sustain combustion, or burning. It is well that so much of the air is nitrogen, for if the greater part of the air were oxygen, any fire, when once started, would burn so rapidly and fiercely that it could not be controlled. The large percentage of nitrogen acts as a sort of check on burning and so, to increase the rate of burning, it is necessary to create a draft, so as to circulate more air and so bring more oxygen in a given time to the point where the burning is going on.

73. Carbon.—The element that forms the larger part of coal is carbon. After the gases have been driven off from coal, the hard coke remaining consists largely of pure carbon. At ordinary temperatures it will not combine with any of the other elements to form chemical compounds. But if raised to a high temperature it will combine very readily with oxygen, for which it has a strong liking, or affinity.

THE COMPOUNDS, COAL AND WOOD

74. Coal.—Coal is a compound that consists of carbon, hydrogen, oxygen, nitrogen, sulphur, and iron in connection with other substances. The part of the coal that burns consists of the carbon, hydrogen, and sulphur; but as the sulphur is looked upon as an impurity in coal, and as its percentage is small when compared with the percentages of carbon and hydrogen, only the carbon and hydrogen will be considered as the parts of the coal that produce heat by their burning. The compounds of hydrogen and carbon in coal, or the hydrocarbons, are of a very complex nature and exist as gases, the principal one of which is methane, and also as a heavy tarry liquid. This tar, when heated in the firebox, is decomposed into carbon and hydrocarbon gases of different kinds. As the actions that take place in the burning of these hydro-

carbons are too complicated to be within the scope of this paper, the burning of methane alone will be considered in connection with the combustion of coal.

75. The two main classes of coal are hard coal, or anthracite, and soft coal, or bituminous coal. It is customary to state the composition of a coal by giving the percentages of fixed carbon, volatile matter, moisture, and ash that it contains. All coal contains moisture, which may be there when the coal is mined or may get into it during or after transportation. The ash is the refuse that is left after the coal is burned, and consists of clay, sand, iron, and other substances that do not burn. The **volatile matter** includes all the gases and vapors that are driven off when a sample of dry coal is heated without burning. The **fixed carbon** is the carbon contained in the solid mass of coke that remains after the gaseous constituent, or volatile matter, has been driven off.

As a very general average, the composition of anthracite may be taken as follows:

Constituents	Per Cent.
Fixed carbon	83
Volatile matter	4
Moisture	3.5
Ash	9.5

The average composition of bituminous coal will fall within the following limits:

Constituents	Per Cent.
Fixed carbon	40 to 61
Volatile matter	27 to 39
Moisture	1 to 17
Ash	6 to 17

Carbon, it will be observed, is the chief constituent of coal. It forms the solid part, or that which remains after the volatile matter has been distilled off by heating. The ash is made up of the incombustible impurities, such as slate, bone, iron, and some sulphur. The iron and sulphur in coal are often found combined in the form of a compound called *iron pyrites,* which

TABLE II

COMPOSITION AND HEATING VALUES OF AMERICAN COALS

(United States Geological Survey)

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alabama	Horse Creek	Horse Creek	B	L N	1.55	32.10	53.71	12.64	.73	12,958
Alabama	Carbon Hill	Jagger	B	L N P	2.58	33.15	51.74	12.53	1.02	12,449
Alabama	Garnsey	Underwood	B	R	2.72	20.46	53.46	14.36	.55	12,461
Alabama	Belle Ellen	Youngblood	B	R	6.43	28.56	52.09	12.92	1.08	12,395
Alabama	Lehigh	Black Creek	B	R	5.51	25.05	53.28	16.08	1.40	11,932
Alabama	Dolomite	Pratt	B	R	2.86	25.80	63.98	7.36	.59	14,440
Arkansas	Bonanza	Jenny Lind	S B	L	.74	16.26	73.66	9.34	1.90	13,961
Arkansas	Denning	Spadra	S B	S	1.79	14.36	73.52	10.33	1.68	13,402
Arkansas	Coal Hill	Denning	S B	L S	1.28	12.82	73.69	12.21	2.01	13,406
Arkansas	Huntingdon	Huntingdon	S B	L	1.17	17.83	68.12	12.88	1.27	13,460
Arkansas	Midland	Hartshorn	S B	L	5.47	16.27	66.57	11.69	2.02	12,690
California	Tesla	Tesla	L	R	18.51	35.33	30.67	15.49	3.05	8,105
California	Stone Canyon		B	R	4.86	47.74	41.03	6.37	4.26	12,727
Colorado	Lafayette	Laramie	B L	R	13.49	37.11	43.03	6.37	.58	10,546
Colorado	Sopris	Sopris	B	R	1.26	31.03	53.39	14.32	.64	12,929
Colorado	Bowen	Walsen	B	R	1.41	31.52	49.16	17.91	.68	12,127
Colorado	Rugby	Cameron	B	S	1.73	35.72	48.36	14.19	.81	12,366
Colorado	Berwind	Berwind	B	R	1.66	33.24	51.57	13.53	.64	13,019
Colorado	Oak Creek	Yampa	B	R	6.69	36.68	45.88	10.75	1.51	11,561
Colorado	New Castle		B		2.73	38.09	53.60	4.98	.54	13,372
Florida	Orlando	Peat, air dried	P		21.00	51.72	22.11	5.17	.45	8,127

Georgia	Menlo	Little River	B	L	3.80	15.88	65.83	14.49	1.27	12,791
Illinois	O'Fallon	Belleville, No. 6	B	L N	6.28	38.92	41.08	13.72	4.25	11,448
Illinois	Marion	Cartersville, No. 7	B	R	5.96	30.29	52.16	11.59	1.77	12,103
Illinois	Coffeen	Pana, No. 5	B	R	5.13	32.68	47.46	14.73	4.45	11,158
Illinois	Collinsville	No. 7	B	R	10.83	36.24	39.75	13.18	4.53	10,8[illegible]
Illinois	Cartersville	No. 7	B	R L	8.86	31.25	48.23	11.66	2.46	11,902
Illinois	Livingston	No. 5	B	R	12.25	33.76	41.66	12.33	4.42	10,719
Illinois	Zeigler	No. 7	B	L	10.72	29.86	50.06	9.36	.91	11,686
Illinois	Herrin	No. 7	B	L	7.78	29.85	52.39	9.98	1.32	11,959
Indiana	Terre Haute	No. 6	B	R	12.79	35.45	39.67	12.09	3.18	10,899
Indiana	Seelyville	No. 3	B	R	7.88	36.85	41.07	14.20	5.14	11,146
Indiana	Linton	No. 4	B	R	13.58	32.07	46.20	8.15	.91	11,419
Indiana	Linton	No. 5	B	R	10.30	36.31	41.64	11.75	4.23	11,218
Indiana	Brazil	Bottom Bed / Brazil Block	B	S N	16.91	26.85	38.87	17.37	1.89	9,524
Indiana	Maxville	No. 7	B	L	5.24	37.83	45.73	11.20	3.56	12,085
Iowa	Laddsdale	Middle	B	L S	5.21	31.76	46.51	16.52	5.20	11,392
Iowa	Marion Co.	Big Vein	B	R	4.25	37.02	41.74	16.99	5.20	11,129
Iowa	Altoona	Third	B	L	4.52	40.96	38.99	15.53	6.83	11,356
Iowa	Centerville	Mystic	B	L	10.03	37.27	41.22	11.48	4.46	11,227
Iowa	Chariton	Lower	B	R	9.22	32.71	44.52	13.55	3.42	10,989
Kansas	Fleming	Lower / Weir-Pittsburg	B	R	3.74	33.11	50.01	13.14	4.34	12,404
Kansas	Scammon	Weir-Pittsburg	B	R	2.50	33.80	51.25	12.45	5.68	12,900
Kansas	Jewett	Weir-Pittsburg	B	L	9.04	29.69	45.55	15.72	3.72	11,142
Kansas	West Mineral	Weir-Pittsburg	B	L N	4.10	31.65	53.71	10.54	3.77	12,895
Kansas	Atchison		B	L	3.57	37.00	46.80	12.63	8.33	12,337
Kentucky	Straight Creek	Straight Creek	B	L	1.92	36.56	57.08	4.44	1.24	14,319
Kentucky	Earlington	No. 11	B	L	5.36	38.99	46.27	9.38	3.72	12,539
Kentucky	Barnsley	No. 9	B	R	5.85	36.90	46.96	10.29	3.60	12,292

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Kentucky.....	Wheatcroft	No. 11	B	R	2.54	36.08	46.79	14.59	4.67	12,294
Kentucky.....	Sturges	No. 13	B	R	5.46	30.99	55.63	7.92	1.18	13,239
Kentucky.....	McHenry	No. 9	B	N	8.70	35.00	47.34	8.96	3.14	12,078
Kentucky.....	Big Black Mt.	High Splint	B	L	1.60	36.03	58.56	3.81	.69	14,324
Kentucky.....	Near Paintsville	No. 1	B	R	5.12	36.49	55.63	2.76	.57	13,743
Maryland.....	Frostburg	Big Vein	S B	R	.74	18.14	73.83	7.29	.86	14,555
Maryland.....	Near West'nport		S B	R	2.33	16.11	68.43	13.13	1.49	13,255
Missouri.....	Bevier	Bevier	B	R	9.14	34.53	39.02	17.31	5.30	10,451
Missouri.....	Higbee		B	R	12.92	33.64	39.82	13.62	5.03	10,548
Missouri.....	Novinger		B	N	16.36	29.12	35.01	19.51	3.53	9,007
Missouri.....	Barnett		B	R	5.39	44.91	44.47	5.23	5.55	13,529
Missouri.....	Huntsville		B	L	2.49	45.44	38.79	13.28	6.34	12,213
Montana.....	Bridger	Bridger	L	S	8.56	32.36	45.69	13.39	.54	10,685
Montana.....	Red Lodge	No. 1	L	S	7.34	37.92	42.17	12.57	1.10	10,269
Montana.....	Bear Creek	No. 2	L	S	8.21	37.98	47.67	6.14	1.47	11,422
New Mexico...	Blossburg	Raton	B	R	2.72	31.85	50.86	14.57	.69	12,539
New Mexico...	Gibson	Weaver	B L	L S	10.86	35.14	46.90	7.10	.64	11,435
New Mexico...	Van Houten	Raton	B	R	3.45	32.00	47.82	16.67	.73	11,893
North Dakota.	Williston	Cedar Coulee	L	R	16.70	37.10	39.49	6.71	.63	9,491
North Dakota.	Lehigh	Lehigh	L	R	15.42	38.73	33.61	12.24	2.02	9,061
Ohio.....	Mineral City	No. 5	B	L	4.49	40.55	47.43	7.53	2.93	13,291
Ohio.....	Bellaire	No. 8	B	R	4.14	39.30	47.18	9.38	3.96	13,381

Ohio.....	Near Wellston	No. 4	B	R	7.71	38.32	42.02	11.95	4.61	11,515
Ohio.....	Shawnee	No. 6	B	R	9.90	33.66	44.86	11.58	1.81	11,279
Ohio.....	Danford	No. 7	B	L	6.65	33.94	48.86	10.55	3.13	12,179
Ohio.....	Dixie	Hocking, No. 6	B	R	7.55	38.00	46.08	8.37	2.84	12,128
Ohio.....	Bradley	No. 8	B	L N	3.53	37.45	49.90	9.12	3.47	13,072
Oklahoma	Panama		S A	R	.64	14.29	76.66	8.41	1.24	14,083
Oklahoma	Henryetta	Henryetta	B	L	3.87	35.73	50.05	10.35	1.99	12,620
Oklahoma	Hartshorne	Hartshorne	B	R	1.70	37.19	49.79	11.32	1.56	12,969
Oklahoma	Edwards	McAlester	B	R	3.45	37.45	47.82	11.28	3.67	12,469
Oklahoma	Lehigh	Lehigh	B	L	4.91	37.79	43.90	13.40	4.02	11,389
Pennsylvania ..	Ellsworth	Pittsburgh	B	L N	1.47	34.83	57.59	6.11	.89	14,155
Pennsylvania ..	Hastings	D	S B	R	.36	22.67	68.78	8.19	1.65	14,062
Pennsylvania ..	Wehrum	B	S B	R	.34	18.12	71.45	10.09	3.88	14,193
Pennsylvania ..	Connellsville	Pittsburgh	B	R	.97	29.09	60.85	9.09	.90	13,952
Pennsylvania ..	Ehrenfield	Lower Kittanning	S B	R	.63	17.32	75.22	6.83	.97	14,706
Pennsylvania ..	White	Upper Freeport	B	R	1.09	28.71	57.87	12.31	1.56	13,406
Pennsylvania ..	Loydell	Miller	S B	R	.38	16.10	74.69	8.83	1.55	14,267
Pennsylvania ..	Huff	Pittsburgh	B	R	.91	29.03	59.57	10.49	1.03	13,738
Pennsylvania ..	Kimmelton	Lower Kittanning	S B	R	.50	17.75	70.12	11.63	2.09	13,783
Pennsylvania ..	Scranton		A	S	2.08	7.27	74.32	16.33	.77	12,472
Rhode Island..	Cranston		G A	R	.42	5.02	75.11	19.45	.07	11,212
Tennessee	Fork Ridge	Mingo	B	R	1.87	33.93	52.71	11.49	1.63	12,942
Tennessee	Brushy Mt.	Petros	B	R	1.35	35.13	53.32	10.20	3.38	13,421
Tennessee	Coalmount	Sewanee	B	L	1.36	27.96	56.22	14.46	.96	12,843
Tennessee	Gatliff	Regal Elock	B	R	2.25	35.68	54.79	7.28	1.02	13,480
Tennessee	Waldensis	Lower Sewanee	B	R	1.02	28.43	55.69	14.86	.80	12,886
Tennessee	Gatliff	Log Mountain	B	R	1.95	36.97	54.05	7.03	1.01	13,734
Texas.....	Hoyt		L	R	9.76	37.51	42.77	9.96	.70	10,228
Texas.....	Olsen		L	R	9.88	36.77	43.65	10.30	1.30	10,287
Texas.....	Crockett		L	R	13.40	42.75	29.00	14.85	1.04	9,358
Utah.....	Price		B		2.34	43.68	48.92	5.06	.57	13,671

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Virginia.....	Pocahontas	No. 3	S B	R	1.63	17.17	75.34	5.86	.75	14,672
Virginia.....	Tom's Creek	Upper Vanner	B	L	.87	32.36	62.19	4.58	.68	14,796
Virginia.....	Blacksburg	Big Seam	A	P	4.80	10.12	67.05	18.03	.63	11,961
Virginia.....	Darby	Darby	B	L	2.40	37.64	55.54	4.42	.81	14,224
Virginia.....	Richlands	No. 4	B	R	.65	24.28	64.77	10.30	1.27	13,963
Washington....	Renton		B L	R	5.20	36.54	45.68	12.58	.80	11,291
Washington....	Roslyn	Roslyn	B	L	1.88	36.97	48.73	12.42	.38	12,751
Washington....	Carbonado	No. 3	B	R	4.66	29.07	50.31	15.96	.45	12,132
Washington....	Taylor	No. 4	B	R	6.20	34.20	41.37	18.23	.69	10,888
West Virginia..	Kingmont	Pittsburgh	B	R	1.35	36.92	55.36	6.37	.90	14,164
West Virginia..	Clarksburg	Pittsburgh	B	R	1.12	37.65	52.60	8.63	2.56	13,937
West Virginia..	McDonald	Sewell	S B	R	.68	23.28	70.91	5.14	.91	14,765
West Virginia..	Winifrede	Winifrede	B	R	1.50	37.16	56.39	4.95	1.35	14,247
West Virginia..	Rush Run	Fire Creek	S B	R	.64	21.74	72.53	5.09	.66	14,942
West Virginia..	Big Sandy	No. 8	S B	R	.62	18.05	74.38	6.95	.69	14,733
West Virginia..	Page	Ansted	B	R	1.17	31.87	62.95	4.01	.91	14,821
West Virginia..	Powellton	Powellton	B	R	1.01	29.53	62.67	6.79	.80	14,171
West Virginia..	Bretz	Bakerstown	B	R	1.00	27.99	62.68	8.33	1.49	14,225
West Virginia..	Bretz	Upper Freeport	B	R	.98	28.72	61.87	8.43	.90	14,139
West Virginia..	Monarch	Cedar Grove	B	R	1.58	35.21	55.50	7.71	1.24	13,757
West Virginia..	Coalton	Roaring Creek	B	L	.65	29.20	59.97	10.18	.99	13,828
West Virginia..	Springhill	Black Band	B	L	1.95	36.24	54.42	7.39	.66	13,694
Wyoming.....	Hanna		B L	R	9.21	45.27	42.04	7.48	.29	11,009
Wyoming.....	Rock Spring		B L	R	6.00	38.69	51.68	3.63	.86	12,519
Wyoming.....	Cambria		B	R	2.73	37.61	37.40	22.26	4.17	10,364
Wyoming.....	Kemmerer		B L	R	8.68	41.31	46.49	3.52	.55	11,621
Wyoming.....	Monarch		B L	R	17.69	37.96	39.56	4.79	.63	10,355

is largely responsible for the formation of clinkers. Soft coal contains a much smaller percentage of fixed carbon than hard coal and a correspondingly greater amount of volatile matter. The parts of the coal that burn and give off heat in burning are, taken together, known as the **combustible.**

76. Calorific Value.—The value of a coal as fuel depends on the quantity of combustible that it contains and on the **calorific value,** or **heating value,** which is the quantity of heat developed by the complete combustion of one pound of the coal. The calorific value cannot be measured in pounds or gallons, like solids or liquids, because heat is not a substance; therefore, it is necessary to measure the heat developed by the effect it produces, and this is commonly done by noting the number of degrees rise of temperature produced in a known quantity of water by the heat.

77. If a pound of water at 39.2° F. is heated until its temperature is one degree greater, or 40.2° F., the quantity of heat added to the water is one **British thermal unit,** abbreviated B. T. U. This is the unit by which heat is usually measured, just as the inch is the unit for measuring short lengths and the gallon for measuring liquids. Thus, the British thermal unit is the quantity of heat required to raise one pound of water one degree Fahrenheit. So, to find the calorific value of a fuel, it is only necessary to burn a pound of it and observe the rise of temperature that the heat of burning produces in a known weight of water. For example, suppose that the heat developed by burning a pound of a certain coal was sufficient to heat 200 pounds of water from 40° F. to 108° F., or an increase of 68° F. The heating value of that coal then must be $68 \times 200 = 13{,}600$ B. T. U. In other words, the product of the rise of temperature and the weight of water is the heating value per pound.

78. The calorific value of a pound of carbon burned completely is 14,500 B. T. U. and of hydrogen is 63,200 B. T. U. Coals, being made up of carbon and hydrogen in varying proportions, have different heating values, depending on the relative amounts of carbon and hydrogen. In recent years it has

TABLE III

COMPOSITION AND HEATING VALUES OF CANADIAN COALS

(Canadian Department of Mines)

Field	Town	Mine	Seam	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alberta:										
Edmonton	Strathcona	Strathcona		L	22.7	41.0	47.6	11.4	.4	10,728
Edmonton	Edmonton	Parkdale		L	22.5	37.8	51.3	10.9	.4	10,908
Edmonton	Edmonton	Standard		L	23.5	42.0	49.9	8.1	.4	11,358
Belly River	Taber	Taber		L	13.0	36.0	49.9	14.1	1.4	11,034
Belly River	Lethbridge	Galt		L	8.4	37.5	51.5	11.0	.8	11,719
Lundbreck	Lundbreck	Lundbreck		R	5.0	30.1	40.2	29.7	1.2	9,810
Frank-Blairmore	Passburg	Leitch	Bellevue No. 1	R	1.9	27.0	55.1	17.9	.6	12,240
Frank-Blairmore	Hillcrest	Hillcrest		R	3.0	29.3	55.4	15.3	.6	12,456
Frank-Blairmore	Lille	Lille	No. 1	R	.9	27.6	56.9	15.5	.8	12,384
Frank-Blairmore	Bellevue	Bellevue	No. 1	R	1.7	25.0	58.6	16.4	.5	12,474
Coleman	Coleman	Denison	No. 2	R	2.0	25.1	55.1	19.8	.4	11,718
Coleman	Coleman	Denison	No. 4	R	2.0	23.9	59.9	16.2	.6	12,528
Canmore-Bankhead	Canmore	A No. 1		R	1.2	17.2	70.5	12.3	.8	13,212
Canmore-Bankhead	Banff	Bankhead		P	1.0	11.8	76.0	12.2	.6	13,320
Canmore-Bankhead	Banff			B	1.1	12.6	71.5	15.9	.6	12,672
British Columbia:										
Crows Nest Pass	Michel	No. 3		L	1.4	24.8	62.7	12.5	.5	13,266
Crows Nest Pass	Michel	No. 7		L	1.9	22.6	65.5	11.9	.4	13,356
Crows Nest Pass	Michel	No. 8		L	3.0	24.1	65.7	10.2	.6	13,482
Crows Nest Pass	Hosmer	Hosmer	No. 2	R	1.7	21.3	63.4	15.3	.3	12,708
Crows Nest Pass	Hosmer	Hosmer	No. 6	R	2.6	25.6	62.0	12.4	.6	13,086
Crows Nest Pass	Hosmer	Hosmer	No. 8	R	4.0	28.0	64.5	7.5	.6	13,986
Crows Nest Pass	Fernie	Coal Creek No. 2		R	2.2	26.3	64.7	9.0	.5	13,822
Crows Nest Pass	Fernie	Coal Creek No. 5		R	1.6	24.0	65.2	10.8	.5	13,482
Nicola Valley	Coutlee	Middlesboro No. 1		R	4.4	39.1	46.4	14.5	.9	11,682

Nicola Valley	Coutlee	Middlesboro No. 2		R	2.9	39.0	48.1	12.9	.7	12,068
Vancouver Island	Wellington	Extension		L	1.8	40.1	49.8	10.1	.4	13,158
Vancouver Island	Nanaimo	Esplanade No. 1	Douglas	L	2.2	41.2	48.5	10.3	.9	12,834
Vancouver Island	Nanaimo	Esplanade No. 1	Newcastle	L	2.4	41.5	46.6	11.9	1.3	12,474
Vancouver Island	Cumberland	Union No. 4	Newcastle	L		31.6	56.5	11.9	1.0	12,870
Vancouver Island	Cumberland	Union No. 7	Newcastle	L		28.6	60.1	11.9	.9	12,978
Vancouver Island	Suquash	Suquash				34.3	42.7	23.0	1.0	11,106
New Brunswick:										
Grand Lake	Minto	Kings		L	1.3	32.2	53.4	14.4	5.8	12,888
Nova Scotia:										
Sydney	Cape Breton	Port Morien	Gowrie	L		34.7	53.0	12.3	6.4	12,708
Sydney	Glace Bay	No. 7	Hub	L	3.5	30.5	57.6	5.9	2.4	13,860
Sydney	Glace Bay	No. 9	Harbour	L	2.4	38.6	55.5	5.9	3.7	14,004
Sydney	Glace Bay	No. 5	Phalen	L	3.4	35.0	59.5	5.5	1.8	14,040
Sydney	Glace Bay	No. 10	Emery	R	4.0	35.1	53.8	11.1	2.5	13,122
Sydney	Lingan	No. 12	Lingan	R	4.9	37.3	57.9	4.8	1.8	13,788
Sydney	Sydney Mines	Sydney No. 1	Main	L	3.5	37.4	55.4	7.2	2.9	13,770
Sydney	Sydney Mines	Sydney No. 3	Main	L	5.4	39.0	54.3	6.7	2.5	13,680
Inverness	Inverness	Inverness		L	9.3	40.0	49.6	10.4	6.0	12,150
Inverness	Port Hood	Port Hood		L	4.7	37.1	48.3	14.6	7.9	11,772
Pictou	Thorburn	Vale	6 Foot	L	2.1	32.1	50.6	17.3	1.0	12,024
Pictou	Stellarton	Allan Shaft	Foord	R	3.6	33.3	55.4	11.3	.6	13,230
Pictou	Stellarton	Albion	Third	R		29.8	55.5	14.7	1.4	12,852
Pictou	Stellarton	Albion	Cage Pit	R	3.6	31.4	58.1	10.5	.9	13,176
Pictou	Westville	Acadia	Main	L	1.8	26.0	64.8	9.2	.9	13,860
Pictou	Westville	Drummond	Main	L	1.4	24.7	60.8	14.5	2.5	12,960
Springhill	Springhill	No. 2		L	2.8	32.3	58.5	9.2	1.6	13,394
Springhill	Springhill	No. 3		L	2.8	33.5	55.0	11.5	1.8	12,996
Joggins	Chignecto	Chignecto		L	3.6	41.0	45.7	13.3	6.4	12,150
Joggins	River Herbert	Minudie		L	3.8	35.7	48.8	15.5	6.7	11,826
Joggins	Joggins	Joggins		L	1.3	36.6	44.8	18.6	5.4	11,592
Saskatchewan:										
Souris	Taylortown	Taylortown		L	28.6	49.0	42.9	8.1	.6	10,692
Souris	Estevan	Eureka		R	30.9	40.0	43.2	16.8	.5	9,648
Yukon:										
White Horse		Tantalus	Upper	M S		25.0	58.0	17.0	.5	12,060
White Horse		Tantalus	Middle	M S		26.7	54.1	19.2	.5	11,358
White Horse		Tantalus	Lower	M S		27.8	56.0	16.2	.5	12,222

become a general practice to buy coal on a B. T. U. basis—that is, to buy it on the basis of its calorific value expressed in heat units, or B. T. U., per pound, rather than on the grade of the coal or the name of the seam from which it is mined. Table II gives the composition and calorific values of a number of typical coals of the United States and Table III gives similar information for Canadian coals. It is to be noted that coals from the same locality vary considerably in composition and heating value. In these tables the letters used are explained as follows: In the column giving the kind of coal, A indicates anthracite; B, bituminous; B L, black lignite, or subbituminous: G A, graphitic anthracite; L, lignite; P, peat; S A, semi-anthracite; S B, semibituminous. In the column giving the grade of coal, L indicates lump; N, nut; P, pea; R, run of mine; S, slack; and a combination of letters represents a mixture, as, for example, L N refers to a mixture of lump and nut. The letters M S in Table III indicate mine sample; and B indicates buckwheat (anthracite).

In the case of the coals mentioned in Table II, the sulphur in the samples was determined separately; consequently, the sum of the moisture, volatile matter, fixed carbon, and ash is 100 for each kind of coal. In Table III, the sum of the volatile matter, fixed carbon, and ash is 100 for each coal, as the moisture and sulphur were determined separately. On account of this difference in methods of analysis, the values of the corresponding percentages, in the two tables cannot be compared directly.

79. Wood.—As a fuel, wood is divided into two classes: the hard woods, such as maple, oak, hickory, etc., and the soft woods, such as pine, birch, poplar, etc. The value, as fuel, of equal weights of different woods, when equally dry, is very nearly the same. In other words, 1 pound of maple is no better for fuel than 1 pound of pine or poplar, provided that both contain the same percentage of water. Water in fuel is very detrimental, every 10 per cent. of moisture reducing its value as a fuel about 12 per cent.

Wood cut in winter will retain, by the end of the following summer, about 40 per cent. of its water, while, after several

years in a dry place, it still retains from 15 to 20 per cent. of it. If wood that has been thoroughly deprived of all moisture is exposed to the outside atmosphere, it will absorb about 5 per cent. of moisture in 3 days, after which it will continue to absorb moisture until it contains about 16 per cent.; it will then absorb no more.

The chemical composition of the various woods is nearly the same, and is about as follows for ordinary fire-wood:

	Per Cent.		Per Cent.
Carbon	37.50	Nitrogen	.75
Hydrogen	4.50	Water	25.00
Oxygen	30.75	Ash	1.50

Two and one-half pounds of good dry wood is generally assumed to evaporate as much water as 1 pound of good coal. A *cord* of wood consists of a pile 4 feet wide, 4 feet high, and 8 feet long.

MIXTURES

80. Definition.—A **mixture** may consist of two or more elementary substances, or compound substances, or both elementary and compound substances, mixed together, but not combined chemically. For example, gold and silver filings may be mixed together to form a mixture; iron filings and sand mixed together form another example; salt water is another instance of a mixture, while the atmosphere forms, perhaps, the most familiar example of all. Air is a mechanical mixture, consisting of twenty-three parts, by weight, of oxygen to seventy-seven parts of nitrogen. These gases are not combined chemically—they are simply mixed together.

81. Air.—The atmosphere consists of a fluid called **air,** that completely surrounds the earth to an estimated height of about 40 miles. It is held in place by its own weight. The weight of the atmosphere is such that it exerts a pressure of 14.7 pounds per square inch at the sea level—a pressure sufficient to balance a column of mercury 30 inches high, or a column of water 34 feet high. This pressure is sufficient to force the air into all holes, crevices, and porous substances, so

that it penetrates the earth to a considerable depth, its density increasing with the depth.

Ordinarily, pure air has no color, taste, or odor; it consists chiefly of a mixture of 4 volumes of nitrogen and 1 volume of oxygen, or, by weight, of about 3.5 parts of nitrogen and 1 part of oxygen. It is through the medium of the atmosphere that the oxygen so necessary to animal and vegetable life, and to the process of combustion, is furnished in its free state. At 62° F., 13.14 cubic feet of air weighs 1 pound.

THEORY OF COMBUSTION

GENERAL PRINCIPLES

82. Definition.—Combustion, or burning, as it is properly called, is a very rapid chemical combination of oxygen of the air with any combustible material, producing both heat and light. Oxygen has a very strong affinity for most elements, and especially for carbon, with which it combines very rapidly whenever they come in contact with each other at a sufficiently high temperature. The more rapid the combination, the greater is the quantity of heat given off in a unit of time, and consequently the higher the temperature produced.

83. The combustible substances in coal, wood, oil, etc. are carbon and hydrogen. The combustion of fuel, therefore, is the rapid chemical combination of the carbon and hydrogen in the fuel with the oxygen of the air. In order to bring about combustion, three conditions are necessary: first, the combustible or fuel; second, air containing the oxygen needed to support combustion; and third, a sufficiently high temperature to cause the combustible elements to start to burn. The temperature to which a combustible substance must be heated before it will begin to burn is called the **igniting temperature.** Each substance has its own igniting temperature, that of coal being in the neighborhood of 1,800° F.

84. Illustration of Combustion.—A familiar illustration of the process of combustion is furnished by the lighting

and burning of a match. The match may be considered as the fuel, the oxygen is supplied by the air, and the substance forming the tip of the match is employed to bring the wood of the match to the igniting temperature. The igniting temperature of the chemical on the tip of the match is much lower than that of the wood; therefore, when the match is struck on a rough surface the friction between the head and the rough surface generates enough heat to raise the temperature of the chemical to the igniting point and so sets it on fire. Its burning in turn raises the temperature of the wood to the igniting temperature, or about 1,000° F. This takes place almost instantly, with the result that the wood and the oxygen start to combine, and the match is said to burn. It will be noticed, however, that the entire surface of the match is not ignited at one time, but that it first begins to burn next the chemical on the tip, and gradually burns toward the other end of the match. The reason for this is that only a portion of the wood near the flame is heated to the igniting temperature. This takes fire, and heats another portion of the wood nearest it to the igniting temperature, which in turn burns, and so on gradually until the match is consumed.

85. Products of Combustion.—The combustible elements in coal are principally carbon and hydrogen, for both of which oxygen has a strong affinity; however, the affinity of oxygen for hydrogen is stronger than that of oxygen for carbon. The result is that when the hydrocarbons in fuel are broken up into carbon and hydrogen, the hydrogen burns first, because the oxygen unites with it in preference to uniting with the carbon. The burning of the hydrogen in coal results in the formation of water, whose chemical formula is H_2O. This formula indicates that two atoms of hydrogen combine with one atom of oxygen to form one molecule of water, or H_2O; but as the firebox is at a high temperature, the water thus produced is converted into steam by the heat and escapes through the stack, along with the smoke and other gases. Steam is therefore the product of the combustion of the hydrogen contained in the fuel.

86. When carbon burns, it may produce either or both of two different gases, depending on the conditions under which combustion takes place. Suppose that the amount of air supplied to the coal is sufficient to furnish two atoms of oxygen for every atom of carbon in the fuel. Then the carbon will combine with the oxygen in the proportion of one atom of carbon to two atoms of oxygen, and each of these combinations results in the formation of a molecule of CO_2, which is the chemical formula of **carbon dioxide.** This is a colorless, tasteless, odorless gas. Whenever there is enough oxygen present, carbon will always burn to carbon dioxide. This gas represents the product of the complete combustion of carbon; that is, the carbon has combined with as much oxygen as it can possibly take up. Carbon dioxide is a dead gas; that is, it cannot be burned, because it is the result of a combustion that is complete.

87. If the quantity of air supplied is too scanty, the result will be incomplete combustion of the carbon. Under such conditions there will not be enough oxygen present to supply each atom of carbon with two atoms of oxygen, and so these two elements will unite in another proportion. Each atom of carbon will unite with one atom of oxygen to form one molecule of **carbon monoxide,** the chemical formula for which is CO. In other words, the carbon combines with only *half* as much oxygen as when it burns to carbon dioxide. Therefore, carbon monoxide is the product of the incomplete combustion of carbon. It also is a colorless, tasteless, odorless gas; but it is different from carbon dioxide because it can be burned. If, after carbon monoxide is formed, it is mixed with a fresh supply of air at a sufficiently high temperature, it will take up additional oxygen and burn to carbon dioxide. This means that each molecule of CO will take up one more atom of O, or oxygen, and thus become CO_2, or carbon dioxide.

88. There is another way in which carbon monoxide may be formed. If a deep fire is carried on a grate, some of the carbon at the bottom of the fire will burn and produce carbon dioxide and this gas will be carried by the draft up through the fire. In the heart of the fire bed there will be a layer of hot

fuel that will be practically pure coke, which consists of carbon without any gases in it. The carbon-dioxide gas, rising and mixing with this hot coke, is broken up, or decomposed, by the heat, into carbon monoxide and free oxygen. The oxygen thus set free combines with some of the carbon in the coke and forms carbon monoxide, so that the net result is that the carbon dioxide is converted into carbon monoxide by taking up additional carbon. This is a very common action in the fire on a locomotive grate. As the monoxide rises into the firebox, however, it is mixed with fresh air admitted above the fire and so is burned to carbon dioxide before it can escape to the stack.

89. As carbon monoxide is capable of being burned, it should not be allowed to escape; otherwise, it will carry away combustible matter and so cause a direct loss. The object should be to burn all carbon to carbon dioxide, as by so doing the greatest possible amount of heat is obtained from the combustion. If a pound of carbon is given enough air to enable it to burn to carbon dioxide, it will yield 14,500 B. T. U. But if the air supply is cut down so that it can burn only to carbon monoxide, the amount of heat developed will be only 4,400 B. T. U. In other words, the incomplete combustion of carbon results in a direct loss of 10,100 B. T. U. In the first case, one part of carbon combines with two parts of oxygen and forms carbon dioxide, which produces a great amount of heat; and in the second case, one part of carbon combines with only one part of oxygen and forms carbon monoxide, producing only one-third as much heat. With half enough oxygen it does only one-third the work that it could do with sufficient oxygen, and oxygen is free—it costs nothing.

90. To change one pound of carbon into the best heat-producing gas takes, theoretically, about 152 cubic feet of air. If half this amount is supplied, the pound of carbon will only use the oxygen contained in 76 cubic feet of air, and will only be one-third as valuable. In each case the same amount of coal will be used, but in the latter case, on account of imperfect burning, only one-third the amount of heat will be generated,

and so only one-third the amount of water will be changed into steam, and steam is what is wanted. At the same time an excess of smoke will be made, and smoke is not wanted. Oxygen is free, while coal costs money; therefore, enough oxygen should be supplied by the air to make perfect combustion and save coal.

91. To follow up this process, it is readily seen that if all the carbon, both fixed and gaseous, could be supplied with all the oxygen needed to change it into carbon dioxide, it would evaporate the same amount of water into steam that 3 pounds of carbon would in case it had so small a supply of oxygen that it could only make carbon monoxide. With a full supply of oxygen, a saving of two-thirds of the coal would, theoretically, take place. But it never happens that all the carbon changes into the very hot gas, as the fluctuating conditions of the supply of coal and air to the fire prevent ideal proportions, so that the fireman must be content with saving as much as possible.

AIR REQUIRED FOR COMPLETE COMBUSTION

92. Carbon.—To burn carbon completely, twelve parts of it, by weight, must combine with thirty-two parts of oxygen; therefore, for every pound of carbon burned, $32 \div 12 = 2.67$ pounds of oxygen must be supplied. As only about 23 per cent. of the air is oxygen, $2.67 \div .23 = 11.6$ pounds of air must be supplied for every pound of carbon consumed; that is, 11.6 pounds of air contains 2.67 pounds of oxygen, and, theoretically, should supply sufficient oxygen to completely burn 1 pound of carbon. The remainder of the 11.6 pounds of air, viz., 8.93 pounds of nitrogen, passes off with the $2.67 + 1 = 3.67$ pounds of carbon dioxide, as the products of combustion.

93. Hydrogen.—The hydrogen of the fuel combines in the proportions, by weight, of two parts of hydrogen to sixteen parts of oxygen, forming water, which, of course, is in the form of vapor. One pound of hydrogen therefore requires $16 \div 2 = 8$ pounds of oxygen for complete combustion. Since

TABLE IV

AIR REQUIRED FOR COMBUSTION OF VARIOUS SUBSTANCES

Combustible	Weight of Oxygen Required to Burn 1 Pound of Combustible Pounds	Quantity of Air at 60° F. Required to Supply the Necessary Oxygen*		Products of Combustion Pounds
		Pounds	Cubic Feet	
One Pound of				
Carbon, burning to carbon dioxide	2.670	11.60	152	3.670 carbon dioxide and 8.93 nitrogen
Carbon, burning to carbon monoxide	1.335	5.80	76	2.335 carbon monoxide and 4.465 nitrogen
Carbon monoxide, burning to carbon dioxide	.570	2.48	33	1.570 carbon dioxide and 1.91 nitrogen
Hydrogen	8.000	34.80	457	26.80 nitrogen and 9 water
Methane (carbureted hydrogen)	4.000	17.40	230	2.745 carbon dioxide, 13.405 nitrogen, and 2.25 water
Average coal	2.530	11.00	140	2.980 carbon dioxide, 8.52 nitrogen, and .45 water
Wood	1.400	6.08	80	1.830 carbon dioxide, 6.08 nitrogen, and .546 water
Petroleum	3.460	15.00	197	3.170 carbon dioxide, 11.55 nitrogen, and 1.28 water

*To determine the quantity of air, in cubic feet, from the weight, in pounds, multiply by 13.14.

each pound of air contains .23 pound of oxygen, $8 \div .23 = 34.8$ pounds of air will be required for the complete combustion of 1 pound of hydrogen. The products of combustion will be $34.8 - 8 = 26.8$ pounds of nitrogen, and $8 + 1 = 9$ pounds of water.

94. Carbon Monoxide.—The combustion of 1 pound of carbon, to form carbon monoxide, requires but half as much oxygen as would be required to form carbon dioxide; therefore, but half the air is required. Since it requires 2.67 pounds of oxygen, or 11.6 pounds of air, to burn 1 pound of carbon to carbon dioxide, to burn it to carbon monoxide would require 1.335 pounds of oxygen, or 5.8 pounds of air, and the products of combustion would be 2.335 pounds of carbon monoxide and 4.465 pounds of nitrogen.

95. Carbon Dioxide.—Carbon monoxide, in burning to carbon dioxide, combines with oxygen in the proportions, by weight, of twenty-eight parts of carbon monoxide to sixteen parts of oxygen. One pound of carbon monoxide therefore requires $16 \div 28 = .57$ pound of oxygen, or $.57 \div .23 = 2.48$ pounds of air, for complete combustion. The products of combustion in this case are: $1 + .57 = 1.57$ pounds of carbon dioxide, and $2.48 - .57 = 1.91$ pounds of nitrogen.

The theoretical quantities of oxygen and of air necessary for complete combustion of various combustibles, together with the products of combustion in each case, are given in Table IV.

HEAT OF COMBUSTION

96. When carbon burns to carbon dioxide, it combines with the greatest amount of oxygen possible, and therefore produces its greatest quantity of heat; when it burns to carbon monoxide, it combines with but half the oxygen possible, and produces less than one-third the heat that would be generated were it burned to carbon dioxide. This is shown in Table V, which gives the total number of heat units produced by the complete combustion of various combustibles.

By completely burning the carbon, 14,500 heat units is produced, while if it is only burned to carbon monoxide, only

TABLE V
CALORIFIC VALUES OF VARIOUS COMBUSTIBLES

Combustible	Total Heat of Combustion of 1 Pound of Combustible B. T. U.
One Pound of	
Hydrogen	62,000
Carbon, burned to carbon monoxide	4,400
Carbon, burned to carbon dioxide	14,500
Carbon monoxide, burned to carbon dioxide	10,100
Methane (carbureted hydrogen)	23,500
Coal (average composition)	14,100
Wood	7,950
Petroleum	21,000

4,400 heat units is produced; that is, 10,100 heat units is wasted for every pound of carbon incompletely burned.

TEMPERATURE OF COMBUSTION

97. Theoretical Temperatures.—In Table V is given the total quantity of heat generated in burning 1 pound of a certain fuel. In Table IV is given the weight and nature of the products of combustion.

The quantity of heat mentioned in Table V will heat the gaseous products of combustion to a certain temperature, depending on their weight and on the number of heat units necessary to raise 1 pound of the gases 1° F. Of course, as the weight and nature of the products of combustion differ for different fuels, the temperatures due to their combustion will differ.

The theoretical temperature of combustion of the fuels in Table VI has been calculated on the assumption that just

enough air for complete combustion is supplied, no allowance being made for losses of heat. These theoretical temperatures are never attained in practice, for the following reasons: Com-

TABLE VI

THEORETICAL TEMPERATURES OF COMBUSTION

Combustible	Resulting Temperature of Combustion Degrees Fahrenheit
Hydrogen	5,750
Carbon, burning to carbon dioxide	4,872
Carbon, burning to carbon monoxide	2,668
Carbon monoxide, burning to carbon dioxide	5,367
Methane (carbureted hydrogen)	9,624
Seasoned wood	2,867
Average bituminous coal	4,080
Average anthracite coal	4,170
Coke or charcoal	4,350

bustion is seldom complete; excess of air is always supplied; fuel is never entirely consumed; heat is lost by radiation; and moisture present in the fuel absorbs some of the heat.

PROCESSES OCCURRING IN THE FIREBOX

98. Tearing-Down Process.—There are two processes constantly going on in a locomotive firebox, one of which is called the *tearing-down process* and the other the *building-up process*. The **tearing-down process** is the breaking up of the fuel into its elements, and requires heat. The **building-up process** is the recombination of the elements separated from the fuel during the tearing-down process with the oxygen of the air to form new compounds, and produces heat. Oxygen will not unite with compounds, but only with elements. Coal is a compound consisting chiefly of carbon and hydrogen,

some of the carbon being combined with the hydrogen to form the volatile matter, or hydrocarbons, the remainder being the fixed carbon. The hydrocarbons must be broken up or separated into their elements, carbon and hydrogen, before oxygen will unite with them. The fixed carbon, as it does not exist in combination with any other element, will burn as soon as it is heated to its igniting temperature.

99. The breaking down or separation of the hydrocarbons, as well as the heating of the fixed carbon to its igniting temperature, requires heat. Therefore, when coal is thrown on the fire, it first absorbs heat. The moisture that may be present in the coal in its natural state, or moisture due to wetting down the coal, is first evaporated, after which the hydrocarbon gases begin to pass off at a temperature of about 400° F. The driving off of these gases continues until the coal is heated to about 900° F., when the greater part of the gases will be given off, the fixed carbon of the coal being left on the grates. As already explained, the hydrocarbon gases are in a compound form, being made up of free carbon and hydrogen, and in this form will not burn. They must be torn down, or separated into their elements, carbon and hydrogen, before burning is possible, and this process requires a far higher temperature than is necessary to distill the gases from the coal. The temperature necessary to break up the hydrocarbon gases into their elements is about 1,800° F., and assuming that the firebox is at this temperature, the hydrocarbon gases are separated into their elements, free carbon and hydrogen. The iron pyrites that may be present in the coal are also heated and separated into iron and sulphur. This completes the tearing-down process, which is accomplished by the expenditure of heat. The building-up process, which results in the formation of heat, will next be considered.

100. Building-Up Process.—It will be assumed first that the conditions in the firebox are such as to insure perfect combustion, which means that the elements present combine in the correct proportions to insure that the maximum temperature will be generated. As already stated, the building-up process

refers to the combination of the elements separated from the fuel, during the tearing-down process, with the oxygen of the air to form new compounds, heat being evolved during the recombination. If the firebox temperature is maintained at or above the igniting temperature of hydrogen and carbon, there will be a combination of oxygen with the hydrogen and carbon set free by the tearing down of the hydrocarbons. When oxygen combines with carbon and hydrogen under the above conditions, certain results always occur in accordance with certain fixed laws. Each atom of carbon under favorable conditions combines with two atoms of oxygen and forms an entirely new compound, known as carbon dioxide, represented by the chemical formula CO_2; and one atom of oxygen combines with two atoms of hydrogen and forms steam, which, when cooled, becomes water, indicated by the chemical formula H_2O. This completes the burning of the carbon and hydrogen of the methane, the only hydrocarbon that will be considered, the products of combustion being carbon dioxide and water vapor.

101. The conditions favorable to the burning of the methane will also result in the breaking up and burning of the other hydrocarbons of the fuel. In order to break up the hydrocarbons, it is necessary to maintain the firebox temperature above 1,800° F.; otherwise, these gases will not be separated into their elements, and will pass off unburned, thus wasting a valuable heat-producing part of the fuel. The carbon and hydrogen will burn at a lower temperature than that required to break up the gases in which they are combined, the igniting temperature of the former being about 930° F. and of the latter about 1,200° F. The remaining carbon, or fixed carbon, of the fuel remains on the grates until consumed, and assuming that there is a high enough temperature and a sufficient supply of oxygen, it unites with oxygen in the same proportion as the free carbon, to form carbon dioxide.

102. During the burning of the hydrocarbons and the fixed carbon, the iron pyrites present separate into the elements sulphur and iron. The sulphur then unites with oxygen and forms a gas known as sulphur dioxide, and the iron combines

with oxygen and forms iron oxide. This latter substance is molten when hot, and in combination with the ashes and other impurities in the coal is largely responsible for clinkers. Although the iron pyrites burn, yet the amount of heat produced by their combustion is small in comparison to the trouble they make in forming clinkers.

103. The tearing down of the hydrocarbon gases into their elements, carbon and hydrogen, and their recombination or building up with oxygen, practically occur instantaneously and if desired may be considered as one and the same event. A small percentage of heat is required to break the fuel into its elementary parts in comparison with the heat produced by the same elements combining with oxygen to form the compounds carbon dioxide and water. These compounds are products of combustion and are gases. If the fuel were composed of carbon and hydrogen only, as in the case of natural gas, for example, and during burning these elements combined completely with oxygen, the gases from burning would be invisible.

104. The fixed carbon of the coal and the carbon of the hydrocarbons do not always burn completely. If there is not enough oxygen present so that each atom of carbon can combine with two atoms of oxygen in the building-up process, some of the carbon will combine with oxygen in the proportion of one atom of carbon to but one atom of oxygen and form another colorless compound gas known as **carbon monoxide,** represented by the formula *CO*. The heat produced during the formation of carbon monoxide is about one-third as much as is produced when carbon burns to carbon dioxide. The unconsumed carbon that escapes due to the absence of oxygen with which to combine is white hot when in the firebox, but when it cools it turns black and forms smoke. Black smoke is then the unburned carbon of the hydrocarbon gases, and represents a serious fuel loss.

105. Fuel-Bed Actions.—Experiments have shown that the fuel bed on which the fixed carbon burns may be divided into three zones, as illustrated in Fig. 4, known as the oxida-

tion, reduction, and distillation zones. As the air passes from the ash-pan through the grates, the oxygen combines with the carbon of the coal and forms carbon dioxide, generating all the heat due to this union. This action occurs in the oxidation zone, which extends three or four inches above the grate line.

The carbon dioxide, after leaving the oxidation zone, passes through the layers of coke in the reduction zone and there each molecule of carbon dioxide takes up another atom of carbon and is reduced to two molecules of carbon monoxide. As the formation of carbon dioxide results in the liberation of heat, so in its reduction or breaking down in the reduction zone it absorbs heat, with the result that a cooling action takes place in

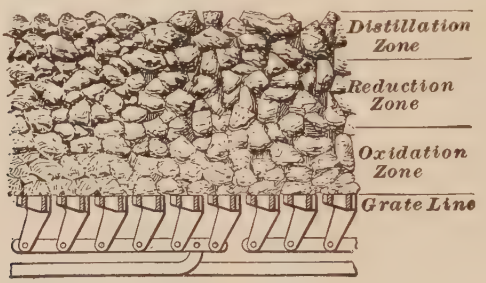

Fig. 4

this zone. The carbon monoxide formed in the reduction zone rises into the distillation zone, where it mingles with the gases that are being distilled, or driven off, from the green coal by the heat, and the mixture of gases rises into the firebox. If there is not sufficient oxygen present to unite with them and burn the carbon monoxide to carbon dioxide, it will pass away in an unburned condition with a resulting loss of heat. If sufficient oxygen is present above the fuel bed, the carbon monoxide will combine with another atom of oxygen and again form carbon dioxide. To burn bituminous coal properly, then, air for the combustion of a portion of the coke can be supplied through the grates, while a sufficient quantity for the combustion of the gases and the upper layers of coal should be admitted above the fire.

106. Proper Air Supply.—The proper supply of air to the fire is one of the most important matters connected with economical firing. It takes about 160 cubic feet of air to supply oxygen for the complete burning of 1 pound of ordinary soft coal, and as each scoopful of coal weighs from 14 to 20 pounds, it will take from 2,200 to 3,200 cubic feet of air to supply the oxygen necessary for its complete combustion. But it is not enough to take in only just sufficient air to furnish the oxygen needed to burn the carbon to carbon dioxide and the hydrogen to water. Every particle of carbon and hydrogen must be surrounded by a liberal supply of oxygen to insure complete combustion, and so 250 cubic feet of air, or nearly 19 pounds, has been found to be about the right amount for a pound of coal, or from 3,500 to 5,000 cubic feet of air for each scoopful. A box car 36 feet long, inside, by 8 feet wide and 8 feet high holds 2,300 cubic feet, which will give some idea of the vast amount of air that must pass through the firebox for each scoopful of coal fired.

107. Quantity of Water Evaporated.—In ordinary locomotive service 7 pounds of water evaporated by 1 pound of coal is a fair average duty; it is possible to raise this amount to 11 pounds. A gallon of water weighs about $8\frac{1}{3}$ pounds. So, if 1 gallon of water is evaporated by the heat developed by burning 1 pound of coal, the results obtained are above the average.

COMBUSTION OF COAL

108. Bituminous Coal.—Coal is a compound substance, consisting chiefly of carbon and hydrogen, in which elements practically its entire heating properties lie. If these are completely burned, the coal will produce its greatest quantity of heat; on the other hand, if they are not completely burned, part of the heat that the coal should produce in burning will pass off as unburned gases and smoke.

When 100 pounds of average bituminous coal is heated, the hydrogen is driven off, taking some carbon with it, in combination, forming 30 pounds of carbureted-hydrogen gas, and

leaving behind about 55 pounds of solid carbon. Thus, for every 100 pounds of coal there is about 55 pounds of solid carbon and 30 pounds of carbureted hydrogen to be burned, the remaining 15 pounds being waste, partly in the gaseous form and partly as solid matter. This means that the coal has .55 fixed carbon and .3 volatile matter. About three-tenths, by weight, of the coal is carbureted-hydrogen gas, which, as seen in Table VI, makes the hottest fire of the fuels there given. The temperature at which this gas breaks up into its elements is rather high, however (about 1,800° F.), and if any part of the firebox is cooled below this, part of the gases will pass away unburned, causing a great waste of heat.

109. Fresh coal, when thrown on the fire, absorbs heat, which raises its temperature and drives off the hydrogen and a portion of the carbon, combined in various chemical unions known as hydrocarbons, of which methane, or carbureted hydrogen, is one. Before burning takes place, this preparatory process of decomposition always occurs, and the products then burn in a certain regular order; the gases burn first, combining with the oxygen of the air to form water and carbon dioxide, while the coke burns last, combining with oxygen to form carbon dioxide.

110. Quantity of Air Required.—For every pound of coal burned in a firebox, enough air must be supplied to furnish sufficient oxygen for the complete combustion of .3 pound of carbureted-hydrogen gas, and .55 pound of carbon. Since, according to Table IV, 152 cubic feet of air is necessary to supply sufficient oxygen to completely burn 1 pound of carbon, it will be seen that $.55 \times 152 = 84$ cubic feet, nearly, must be supplied in burning .55 pound. To completely burn .3 pound of carbureted hydrogen, $.3 \times 230 = 69$ cubic feet of air must be supplied. So that, to completely burn 1 pound of coal, $84 + 69 = 153$ cubic feet of air must be supplied.

This is the theoretical quantity of air required, and it is calculated on the assumption that the air is so intimately mixed with the carbon and gases of the fuel that all its oxygen combines with the fuel. Practical experience, however,

teaches us that the air does not mix very thoroughly with the combustible parts of the coal in the firebox, some of it passing through the tubes and up the stack, without having an opportunity to part with its oxygen. If, therefore, only the theoretical amount of air were admitted to the firebox, it would not supply sufficient oxygen to completely burn the coal, and thus heat would be wasted.

Practical experience in locomotive work, in fact, seems to indicate that about 250 cubic feet (nearly 19 pounds) of air per pound of coal is necessary to secure complete combustion when admitted in the proper manner.

111. If too much air is admitted to the firebox, it wastes heat in two ways: (1) The extra air is heated in the firebox and carries a great deal of heat with it as it escapes through the stack at a high temperature. (2) In order that this increased volume of gases and air may pass through the tubes in a given time, they must acquire a greater velocity, and consequently they will have less time in which to impart their heat to the water.

The effect of admitting too much air to the firebox can very readily be seen by opening the fire-door, for the large volume of cool air thus allowed to pass into the firebox absorbs and carries away so much heat that the steam pressure begins to drop almost at once. The same effect is noticed when holes are allowed to form in the fire.

112. It is impossible to so regulate the thickness of the fire as to allow sufficient air to be admitted through the grates to burn both the coke and also the volatile gases of the coal. The greatest quantity of air is required just after a charge of coal is put in, and, if the fire is sufficiently thin to supply the necessary air at that time, it will supply too much as soon as the gases have been burned. Then, again, as regards facilitating the air supply, the fire would require to be thinnest when the engine was making its greatest effort, and, at such times, the exhaust would be most violent and would tear holes in the fire, through which large quantities of cold air would flow, and so reduce the temperature of the firebox, besides carrying small

pieces of unburned coal into the tubes, thus causing a still further waste.

113. Consumption of Gaseous Products.—It has already been seen that 100 pounds of average bituminous coal produces, in coking, about 55 pounds of solid carbon and 30 pounds of volatile gases. To secure the combustion of the coke or carbon only, would be a comparatively simple matter; it is in the thorough burning of the gases that the chief difficulty is experienced. To burn the gases completely it is necessary: (1) to maintain them at the igniting temperature while in the firebox; (2) to admit sufficient air for their complete combustion; and (3) to admit this air in as small streams as practicable, so that the air and the gases may mix as quickly and completely as possible while in the firebox and at the igniting temperature.

114. The coke can take its own time for burning, as it remains on the grates until consumed. The gases, on the other hand, begin their flight to the tubes the moment they are distilled; they have, consequently, but a fraction of a second in which to mix with the air and burn before they reach the tubes. Time, therefore, has a very important influence on the combustion of the gases, and if they do not have sufficient time to mix completely with the air while in the firebox, and at an igniting temperature, they pass off unconsumed, as no combustion takes place within the tubes. This is why a brick arch aids combustion.

115. Air for the combustion of the gases should not be admitted in large streams, as, for instance, when the fire-door is opened, for in that case it forms a distinct current of cold air that does not mix with the gases but cools them below the igniting temperature, and they pass off unburned. When admitted in small streams, the air is heated quickly and becomes more thoroughly mixed with the gases, and complete combustion is then more nearly secured. The volume of gases is greatest just after coal is put in; the greatest volume of air, therefore, should be supplied at that time, and the supply diminished as the volume of gases generated diminishes.

116. Temperature in Firebox. The temperature in the firebox must be at about 1,800° F. before the gases will separate into their elements and burn. The maximum temperature attained in the firebox of a locomotive is from 2,000° to 2,500° F., therefore, the difference between the igniting temperature of the gases and the maximum temperature in the firebox is so small, comparatively, that constant care must be exercised to prevent the temperature from falling below 1,800° F. It becomes necessary, therefore, to judge of the temperature in the firebox by the appearance of the fire, for if the temperature is known, the conditions of combustion may

TABLE VII

TEMPERATURES INDICATED BY COLOR OF FIRE

Temperature Degrees Fahrenheit	Appearance	Temperature Degrees Fahrenheit	Appearance
980	Red—just visible	2,010	Dull orange
1,290	Dull red	2,190	Bright orange
1,470	Dull cherry red	2,370	White heat
1,657	Full cherry red	2,550	White welding heat
1,830	Bright red	2,740	Dazzling white heat

be inferred. The appearance of the fire at different temperatures is given in Table VII.

117. The theoretical temperature of combustion of average bituminous coal was given in Table VI as 4,080° F. As just stated, the temperature attained by the combustion of bituminous coal in the firebox of a locomotive is from 2,000° to 2,500° F.; this difference between theoretical and actual temperatures is due to the losses of heat that take place during combustion in the firebox. These losses are as follows: (1) Heat is lost by some of the gases escaping unburned, and by small pieces of coal dropping through the grates or being drawn through the tubes unconsumed; (2) more air is usually supplied than is required for combustion, and, as this

superfluous air and the resultant gases of combustion pass out through the stack, they carry off heat, which reduces the temperature in the firebox; (3) there are losses due to radiation and convection of heat from the boiler; and (4) there is the absorption of heat by the water in the boiler.

The heat absorbed by the water is the chief factor in the reduction of the temperature, and it is due principally to this loss that a higher temperature is not obtained.

SMOKE

FORMATION OF SMOKE

118. **Smoke,** such as is seen issuing from a chimney or from the smokestack of a locomotive, consists simply of water vapor and the gaseous products of combustion, colored with fine particles of carbon; the blacker the smoke, the more carbon is present as coloring matter.

The formation of smoke takes place as follows: When a quantity of fresh bituminous coal is thrown into the firebox, it absorbs heat so rapidly that the temperature there is reduced below that of ignition of the gases, which, as they are driven off from the coal, appear as a dark-yellow or brownish-colored vapor. This vapor is not the same as that which issues from the smokestack, called smoke, but is carbureted-hydrogen gas, colored by tarry matter, sulphur, and other volatile ingredients.

119. When the carbureted hydrogen attains the proper temperature, it ignites and burns as a flame. The hydrogen unites with oxygen and passes off as water vapor, or steam; the carbon liberated is partly consumed, and partly passes away unconsumed as small particles of solid carbon, called **soot.** It is this latter that colors the escaping gases of combustion and forms what is called smoke.

Had sufficient oxygen been present and in contact with the carbon while its temperature was high enough for them to combine, all the carbon would have been burned and the for-

mation of smoke prevented. Smoke once formed is incombustible at firebox temperatures, as the carbon, or soot, will burn only at a very high temperature.

120. Smoke may be formed, even at high temperatures, if there is not sufficient oxygen present to combine with the carbon as it is liberated; or it may form, when sufficient oxygen is present, if the temperature of the flame is cooled below the igniting temperature of the carbon before the oxygen comes into contact with it. The formation of smoke, due to an insufficient supply of air, may be shown by placing a chimney over a lamp flame and then closing either end. The function of a lamp chimney is to produce an upward draft of air, which is deflected against the flame and furnishes a supply of oxygen sufficient to consume all the carbon while it is at a white heat in the flame. If either end of the chimney is wholly or partly stopped up, the flame will at once begin to smoke, because there is not sufficient oxygen coming in contact with it to burn all the carbon, which therefore passes off as soot or lampblack. As soon as the obstruction is taken from the end of the chimney, however, the current of air through it is resumed, and the smoke ceases.

An example of cooling the flame of a gas below the igniting temperature of the carbon, thereby causing it to smoke when an abundant supply of oxygen is at hand, may be furnished by placing a pan of cold water above the flame. The water will absorb heat from the flame so rapidly that the temperature of the flame will be reduced below the igniting temperature of the carbon, which will consequently pass off unconsumed as soot.

PREVENTION OF SMOKE

121. Carbon, in a gaseous state, before it is liberated from the hydrocarbon gases of the coal, is invisible; but if, after the hydrocarbons have been broken up by the heat, the carbon is not burned, and is allowed to cool, it appears in the solid form as black soot, and forms smoke. The formation of smoke, therefore, can be largely prevented by completely burning all the

carbon as it is liberated from the hydrocarbons, so that none will escape in the solid form as soot. All the carbon can be burned if sufficient oxygen is brought in contact with it as it is liberated, and at the igniting temperature. This is the proper method of preventing the formation of smoke, and it will be found very efficient if the coal is fired in small quantities. For instance, if only small charges of coal are fired at a time, and at regular intervals, smoke will be almost entirely prevented.

A good firebrick arch, properly constructed and applied, assists very materially in the prevention of smoke, because it tends to maintain the temperature at or above the igniting temperature of carbon.

It is not practicable to prevent smoke entirely at all times, as, in order to do so, an excess of air must be supplied, which may be more wasteful than if a little smoke were allowed to form.

BOILER ATTACHMENTS
(PART 1)

GAUGES AND INJECTORS

1. We shall now consider the various fittings and appliances that are common to all locomotive boilers as at present constructed, and which may be grouped under the head of **boiler attachments.** Some of them are strictly essential; for example, a means of determining the height of water in the boiler, and also the degree of steam pressure therein; an apparatus for renewing the supply of water in the boiler; a means of lubricating the various working parts, etc. Less strictly necessary, but altogether desirable in present-day practice, are such appliances as sight-feed lubricators, bell ringers, air sanders, etc. Usually the cars of the train are heated by steam from the boiler of the locomotive, the flow therefrom and the regulation of the pressure being controlled by the engineer by means of certain valves placed in the cab.

GAUGES

GAUGE-COCKS AND WATER GAUGE

2. Height of Water.—It is imperative that some means be provided whereby the height of water in the boiler can be determined at any time, and for this reason every boiler is fitted with **gauge-cocks,** and, in most instances, a *glass water gauge*, also. The gauge-cocks are made of brass, and are generally three in number, although four are sometimes used. The center of the lowest gauge-cock is usually placed 3 inches above the highest point of the crown sheet, although

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on some engines it is placed from 4 to 6 inches above the highest point. Whatever its position, it is intended to mark the lowest advisable water level; the water, therefore, should never be allowed to drop below the lowest gauge-cock. The upper gauge-cock is placed just a little above the intended high water level, and the middle cock midway between the two. This brings the gauge-cocks from $2\frac{1}{2}$ to 4 inches apart. The water level should not be carried high enough for the upper cock to discharge water, nor so low that steam will be discharged through the lowest cock. By means of the gauge-cocks, then, it is possible to locate the water level approximately. For example, if the middle cock blows water and the upper one steam, it indicates that there are more than two gauges of water but less than three; if it blows steam and the lowest cock blows water, there is more than one gauge but less than two; if the lowest cock blows steam, there is less than one gauge; while, if the upper cock blows water, there are more than three gauges. Gauge-cocks, however, will not tell us how much less than one gauge there is, nor how much more than three, nor just where the water stands between gauges; all this is the duty of the glass water gauge.

3. Water Gauge.—As shown in Fig. 1 (*a*), the **water gauge** consists of two elbow valves *A* and *B*, communicating with each other by means of the glass tube *C*. This tube is usually $\frac{5}{8}$ inch outside diameter, $\frac{1}{8}$ inch thick, and from 10 to 15 inches long; steam-tight joints are made between glass and metal by means of rubber gaskets. On some engines, the lower valve *A* is so placed that the water is visible at the bottom of the glass at the same height as the center of the lowest gauge-cock; in other cases, it is below that point. The best practice is to use a glass of such a length that it will indicate water levels both above the highest and at the lowest gauge-cocks. With such a gauge, the exact level is known at which the water threatens to expose the crown sheet or to flood the cylinders; and knowing the exact water level, the engineer can attend to the water supply with better judgment.

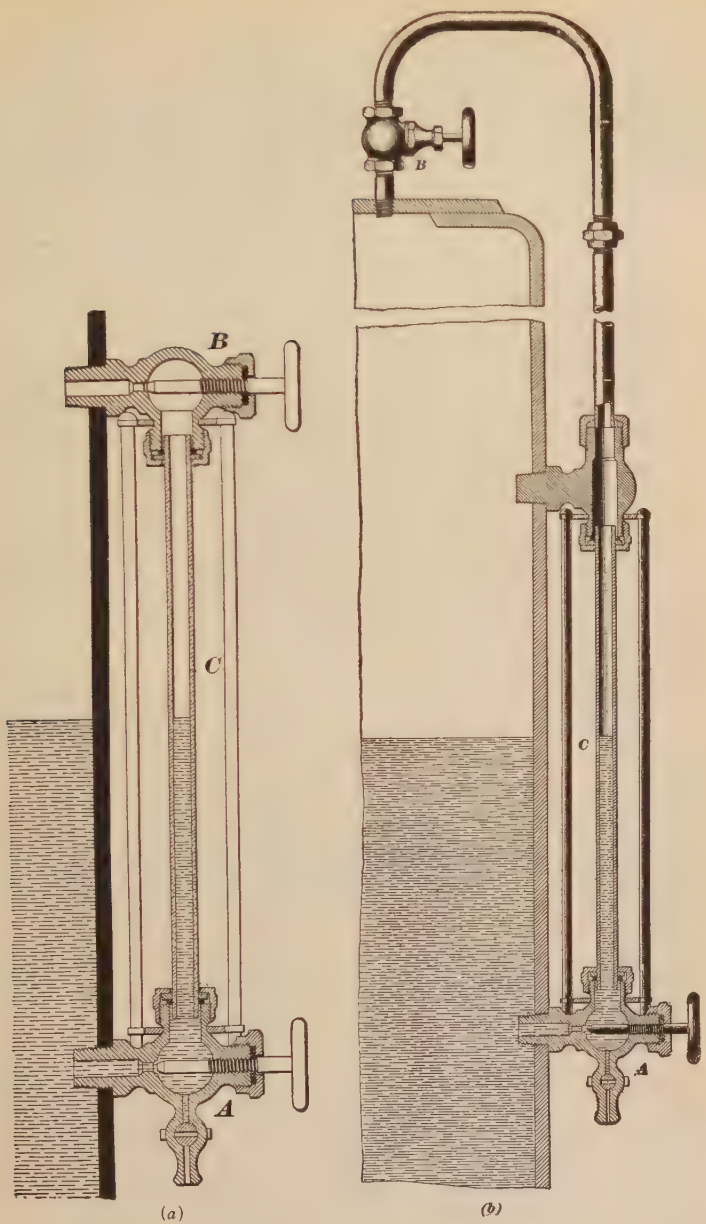


FIG. 1

In the lower part of *A* is fitted a blow-off cock used to blow sediment out of the fitting *A*. When valves *A* and *B* are open, water flows in through valve *A* and assumes a position in the glass on a level with the water in the boiler, thus indicating its height. With the glass in working condition, the water within plays up and down, due to variations of water level caused by the motion of the engine; if it ceases to fluctuate while the boiler is working, the cocks should be examined, as they may be stopped up or closed.

Another type of water glass is shown in view (*b*), in which a copper tube is attached to the upper end at *C* and extends over on top of the boiler, where a globe valve *B* is located, which controls the admission of steam to the top end of the glass. This arrangement provides a supply of condensed water to the glass, which comes down the copper pipe with the steam, prevents the rapid corrosion of the upper end of the glass, and keeps the glass clean by causing a downward flow through it, thus making its action more certain. In another type of water glass, a flat glass is fastened in a metal casing with packing strips and bolts; it will not explode under pressure as do the tubular glasses. The valves for steam and water for the flat glass are exactly like those used with the glass tubes, and the remarks and explanations for one apply to the other.

Reflex Water Gauge.—The reflex water gauge is illustrated in Fig. 1 (*c*) and (*d*). In this type of gauge the water shows dark, while the steam space above the water shows light, as indicated. In the figure, the steam valve is shown at *1*, the water valve at *2*, and the drain valve at *3*.

All that has been said relative to the operation of the water gauges shown in Fig. 1 (*a*) and (*b*) applies also to the reflex water gauge.

When putting the gauge together after having had it apart, do not tighten the bolts up tight until the gauge has become hot; then "follow up" the bolts uniformly so as to take up any slack caused by expansion. Never tighten up a single bolt, or the bolts on one side only. All the bolts must be tightened uniformly and a little at a time

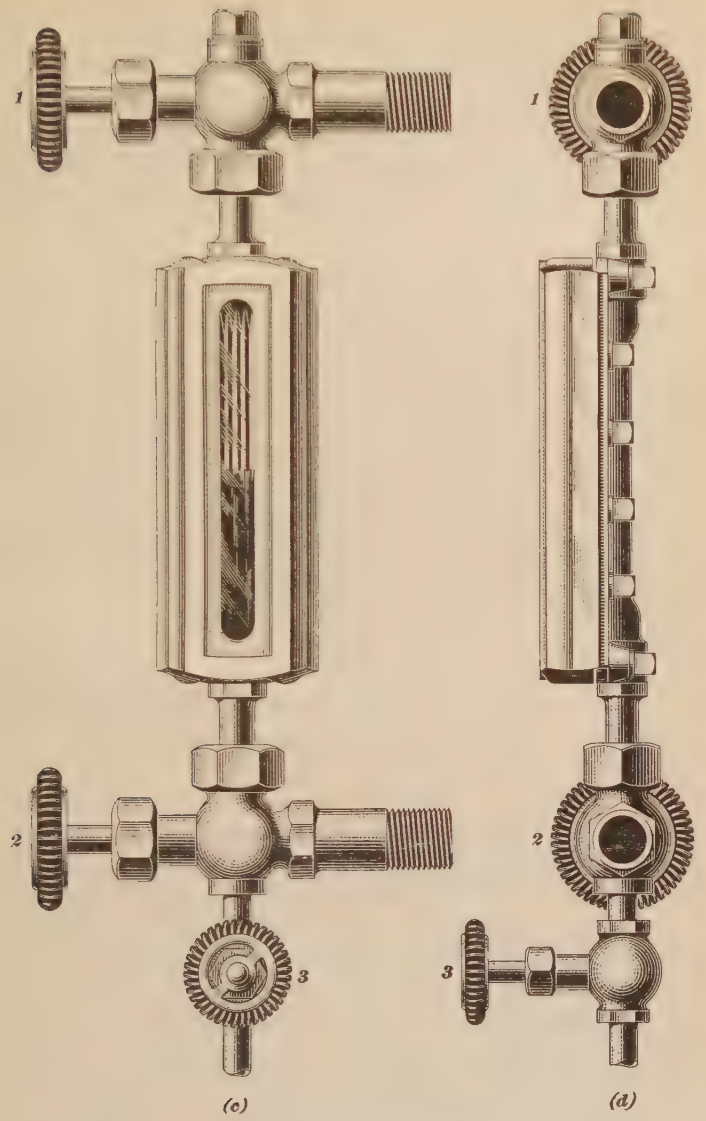


FIG. 1

The bolts should be tightened occasionally, as repeated expansion and contraction due to heating and cooling the gauge repeatedly is liable to loosen the joints and cause leaks. Leakage destroys the glass, and for this reason it must be prevented. When leakage occurs, remove the glass at the very first opportunity. Clean the glass and the joint faces of the frame thoroughly and renew the gaskets. If the gauge cannot be attended to at the time the leak is noticed, shut it off until it can be repaired.

Cuts in the joint face of the glass appear first in the steam end of the gauge. When these appear, the glass should be turned end for end. Placing the cut end on the water end of the glass will usually make the glass serviceable for a time.

The gauges should be blown out after each trip in order to get rid of any mud or other matter that may be injurious to the packing or the glass. Some roads place the drain valve *3* in the top column *4* below the seat of the steam valve *1*, so that by closing valve *1* and opening valve *2*, the glass can be blown out with water instead of with steam. This method is said to give better results than where the drain valve *3* is placed below the valve *2*, as the glass is cleaned by water instead of by steam. Blowing steam past the glass tends to chip and crack the glass, making it opaque. The use of the water prevents this and also decreases the liability of the glass breaking.

4. Water Level.—The gauge glass will not indicate correctly (1) if the upper valve is closed or is stopped up; (2) if the lower valve is closed or is stopped up with scale or mud; (3) if the upper valve is partly closed, or the opening partly stopped up, so as to obstruct the free flow of steam into the glass; (4) if the lower valve is partly closed or the opening partly stopped up with scale and mud, so as to obstruct the free flow of water into the glass. These four cases will be considered separately.

1. If the upper valve is closed or is stopped up, the steam pressure will be shut off from above the water in the glass, and the pressure on the water in the boiler will force sufficient

water into the glass to fill it, and it will remain full regardless of the height of water in the boiler. To test for this defect, open the blow-off cock at the bottom of this valve and close the lower valve. If no steam escapes, it indicates that the passage in the upper valve is stopped up.

2. If the lower valve should accidentally be closed or become stopped up, the water level will not fluctuate in the glass, which will gradually fill up through condensation of the steam. To test for this, close the upper valve, open the blow-off cock, and empty the glass. If no water flows after the glass becomes empty, the lower valve is closed, or else stopped up.

3. The upper valve should always be opened wide enough to insure full boiler pressure on top of the water in the glass. The steam in the glass is constantly condensing, so that there must be a flow of steam into it to maintain the pressure. If the opening through the upper valve is so small as to throttle the steam (whether due to mud or dirt, or to the valve being partly closed), the pressure of steam on the water in the glass will be less than boiler pressure, and the glass will indicate a higher water level than there really is in the boiler. For example, suppose the pressure in the glass .1 pound less than boiler pressure, what effect would it have on the water level in the glass? A column of water 1 inch high, at a temperature corresponding to a pressure of 160 pounds, exerts a pressure on its base of about .032 pound; therefore, for every .032 pound difference in the pressures existing in the glass and the boiler, respectively, the water level in the glass will rise 1 inch above that in the boiler. With a difference of .1 pound, the water level in the glass will rise $\frac{.1}{.032}$, or about 3 inches above the boiler water level. This might lead to serious results if the glass alone were relied on, as the latter might indicate more than a gauge of water when in reality the crown sheet was only barely covered.

4. The lower valve should always be open wide enough to insure a free circulation between the boiler and the glass. Should the valve be partly closed or partly stopped up, the

circulation will be restricted and the glass will not indicate correctly. The supply of condensed water entering the top of the glass will tend to raise the indicated water level.

5. Points to Be Remembered.—Remember that the gauge-cocks and the glass water gauge must be kept clean and in good working order; that, if the water level in the glass is not moving up and down when the engine is working, the glass is not operating properly; that the gauge glass alone should not be depended on, but the glass and gauge-cocks worked in conjunction; that if both the glass and the gauge-cocks become inoperative, the engine is unsafe to run until the gauge-cocks are in order again; that $2\frac{1}{2}$ inches is the least depth of water on the crown sheet that is safe; that less than one gauge, or with the water out of sight in the glass, it is very unsafe, as the exact water level is unknown; that when working steam the water level always rises in the gauge glass and descends when steam is shut off; and that a grade affects the water level.

6. Replacing a Gauge Glass.—First close the lower and then the upper valve, to prevent the escape of water and steam. An old glass can be removed and a new one put in its place by unscrewing the packing nuts. Before putting in a new glass, remove all particles of the old glass and gaskets and blow out the gaskets. Take care not to screw the packing nuts too tight at first, as this is liable to so strain the glass as to cause it to break as soon as it is heated. Screw the nuts down gently at first, even if there is a little leakage for a time; the leaks can be attended to after the gauge is heated without danger of breaking the glass. After replacing a glass, open the drip cock and the steam cock a small amount so as to heat the glass gradually; then open the water cock. Swabbing a glass with oil will prevent it from becoming discolored.

STEAM GAUGE

7. Duty of Steam Gauge.—The duty of the **steam gauge** is to indicate the pressure of steam in the boiler. The essential parts of the form of gauge shown in Fig. 2 are

a brass or copper tube a of elliptical section, bent in the form of a circle as shown, and the toothed quadrant f and small pinion g, by means of which the motion of the tube a is transmitted to the pointer P. The end b of the tube a is fastened into the casting C, and is held stationary; the other end is closed by a cap d and is free to move. This cap is connected to the quadrant f by the rod e, while the quadrant meshes with

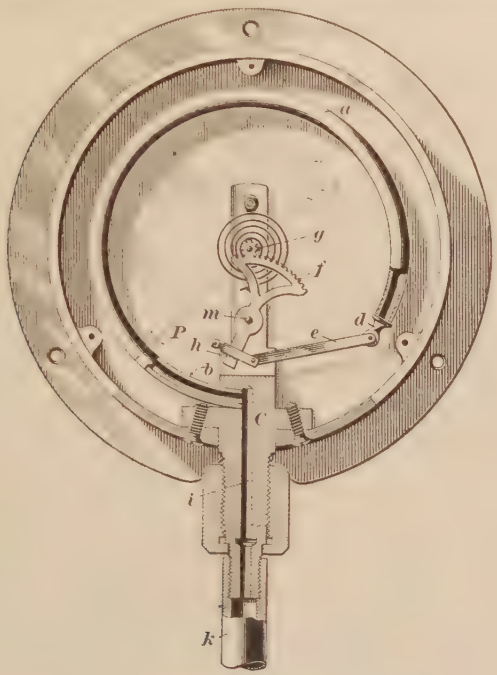


FIG. 2

the pinion g. This pinion is fixed on the same spindle as the pointer P, and the quadrant f is pivoted at m; therefore, if the end d of the tube moves, the movement will be transmitted to the pointer P through the rod e, quadrant f, and pinion g.

The boiler connection is made at k, and, when pressure is admitted to the gauge, it passes up i and enters tube a. The pressure tends to make the tube circular in section, the result being that the tube straightens out and the free end d

moves away from the stationary end *b*. This movement, in being transmitted to the gauge pointer, is multiplied by the mechanism used, so that a small movement at *d* makes the pointer move through a comparatively large space, thus facilitating the reading. The casting *C* is extended upwards, and the various working parts fitted to it; this arrangement gives better results than when parts are fitted to back of case, and permits of the case being removed for the inspection or repair of the inside parts.

8. Testing and Adjusting.—It is very important that the gauge should indicate correctly, and it ought therefore to be tested occasionally, and adjusted if required. To determine whether or not a gauge reads correctly, it may be compared with a gauge that is known to be correct, or it may be tested on a gauge tester. The error in a gauge may be constant at all pressures, reading either too high or too low. For instance, the reading may be always just, say, 4 pounds too high or too low. On the other hand, the error may increase with the pressure, being, say, 2 pounds out when the gauge registers 10 pounds; 4 pounds out when it registers 20 pounds; 6 pounds when registering 30; and so on.

If the error is the same at all pressures it may be corrected by moving the pointer on its spindle. If it varies with an increase of pressure, it may be remedied by altering the ratio of multiplication of the mechanism by changing the position of the adjustable connection *h* with respect to the pivot *m*. Before replacing a gauge, be sure that the gauge pipe is free from all obstructions.

9. Crosby Vertical Reading Dial.—A dial, called the vertical reading dial, Fig. 3, is often used with Crosby gauges. The circle of figures forms the scale, while the large figures in the indicator above the scale (200 in this figure) denote the pressure that the locomotive is authorized to carry in service. The indicator can readily be adjusted to show any number desired so that it can be used with any boiler pressure. Gauges using this dial have two hands, a

large and a small one. These are fastened to the same spindle and are stationary with respect to each other. They are put on as follows: If the boiler is to carry 200 pounds pressure, the indicator will be set to show 200. When the gauge is subjected to 200 pounds pressure the small hand is put on the spindle so as to indicate that amount on the small scale; also, the large hand is put on the same spindle only it points to the number shown in the indicator. When the boiler is carrying the proper amount of pressure, both hands will be indicating the amount and the large hand will be vertical. The large hand, therefore, indicates by position, whereas the small hand indicates the proper amount on the figures of the scale.

FIG. 3

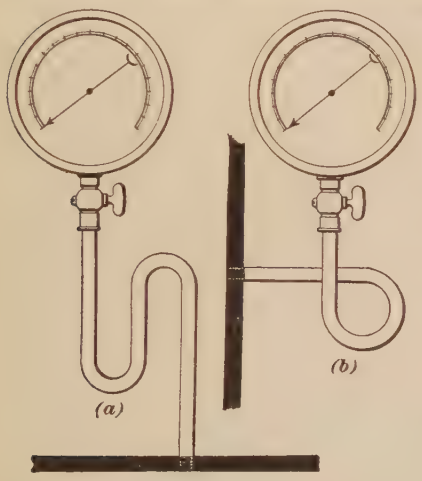


FIG. 4

10. Gauge Pipe. The pipe that connects the gauge to the boiler should be bent in such a way as to prevent the steam from coming in contact with the tube *a*, as the high temperature expands the tube and changes the indication of the gauge. If the pipe is bent as in Fig. 4 (*a*) or (*b*), the bent portion will fill with comparatively cool water condensed from the steam. The part of the pipe above the bend being also filled with water of condensation, the tube will

be protected from the extreme heat, which affects the indications of the gauge. Gauges located at the top of the cab are subjected to extreme heat and never register correctly.

11. Gauge Pressure.—The pressure recorded by a steam gauge is not the actual pressure exerted by the steam on the inside of the boiler, but only the amount by which it exceeds the atmospheric pressure; the pressure thus registered on the gauge is spoken of as the **gauge pressure.** The true, or **absolute, pressure,** as it is called, can be found by adding the pressure of the atmosphere, about 14.7 pounds per square inch, to the gauge pressure. Thus, the absolute pressure is equal to the gauge pressure + 14.7; so that when the gauge shows 160 pounds, the steam inside is really exerting a pressure of 174.7 pounds, 14.7 of which is counteracted by the pressure of the atmosphere on the outside of the boiler, thus leaving us a net pressure in boiler of 160 pounds.

12. Weight of Atmosphere.—That the weight of the atmosphere will balance or support a column of mercury 30 inches high, or a column of water 34 feet high, may readily be seen by filling with mercury a glass tube about 32 inches long and closed at one end. Invert the tube, putting a finger over the open end, so as to prevent the mercury from running out, and place it in a cup of mercury, as shown in Fig. 5. The mercury in the tube will rise and fall a few times, and then come to rest at a height of about 30 inches above the surface of the mercury in the cup. The atmosphere exerts an equal pressure on every square inch of surface of the mercury in the cup, except on that part of the surface occupied by the tube. This pressure is exerted in all directions, and consequently an upward pressure of 14.7 pounds per square inch is exerted on the mercury in the tube. A cubic inch of mercury weighs about .49 pound; an upward pressure, therefore, of 14.7 pounds would support $14.7 \div .49 = 30$ inches of mercury.

A column of water 1 inch square and 1 foot high weighs about .434 pound; if, therefore, a glass tube 35 feet long

were filled with water and inverted in a manner similar to the mercury tube shown in Fig. 5, the upward pressure exerted by the atmosphere on the water in the tube would support a column of water 14.7 ÷ .434 = 34 feet high, nearly.

FIG. 5

13. Vacuum.—The space between the upper end of the tube and the mercury, Fig. 5, is called a **vacuum**, a term used to imply that the space is entirely empty, and contains no substance whatever—solid, liquid, or gaseous. If there were a gas of any kind there, no matter how small the quantity might be, it would expand, fill the space, and exert a downward pressure on the top of the mercury that would cause the column to fall and become shorter, according to the amount of gas (or air) present. This space would then be called a *partial vacuum*, since it would not be entirely devoid of matter. Although the height to which a fluid such as water or mercury will stand or rise in a tube depends on the completeness of the vacuum therein, it must not be supposed that the vacuum "sucks up" or raises the fluid. It is the pressure of the atmosphere on the surface of the fluid outside of the tube that forces the fluid up into the tube and holds it there.

14. Measuring a Vacuum.—The general method of obtaining a vacuum is to pump the air out of a closed vessel by means of a vacuum pump; but a perfect vacuum can never be obtained by this means, although a close approach to it can be made. In fact, while an approximately perfect vacuum has been obtained by other means, a perfect vacuum has never been obtained, and probably never will be.

The amount of vacuum obtained in any vessel may be measured by means of a column of mercury, as will be explained with the aid of Fig. 6, in which *1* is a vacuum

pump. This is very similar to a small force pump, except that the valves *a* and *b* are arranged on the opposite sides of the piston and cylinder wall to what they would be in a force pump. The exhaust pump communicates through pipe *c* with an air-tight vessel *2* that opens to the atmosphere through the cock *d*. *3* is a glass tube more than 30 inches long and closed at one end, the same as in Fig. 5. This tube *3* has been filled with mercury, then inverted, and after that placed in the mercury *e*, as shown. Now, if the cock *d* is open, so

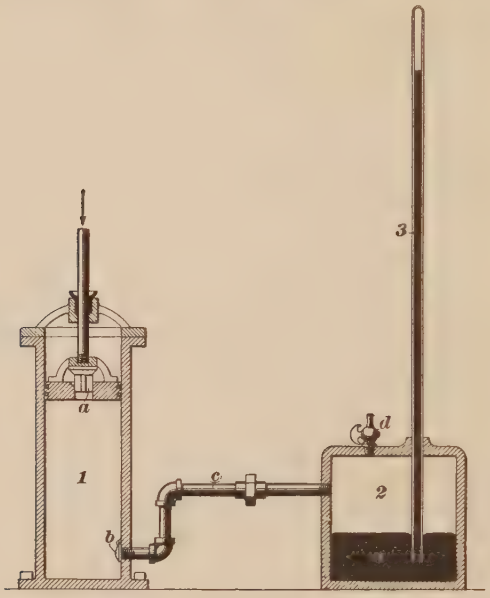


FIG. 6

that the vessel *2* is filled with air at atmospheric pressure, the pressure on top of the mercury will force the latter up the tube to a height of 30 inches. Suppose that the cock *d* is then closed, and part of the air pumped out of the vessel; the remaining air will exert less pressure on the mercury *e*, and consequently the column in the tube will fall from 30 inches to a height corresponding to the pressure in the vessel. If still more air is pumped out, the height of the column will be lowered still more, and so on, until, if

all the air were removed from vessel 2 and a perfect vacuum existed therein, the mercury in tube 3 would be on a level with the mercury *e*. To lower the mercury column from 30 to 29 inches, therefore, one-thirtieth of the pressure in the vessel must be removed; in other words, instead of having 30 inches of pressure* in the vessel there will be only 29 inches of pressure and 1 inch of vacuum. When the column stands at 25 inches there will be 25 inches of pressure and 5 inches of vacuum; when the column falls to 20 inches there will be 20 inches of pressure and 10 inches of vacuum, and so on. It will thus be seen that the amount of vacuum in the vessel is expressed as the number of inches the column has fallen from its maximum height, 30 inches. Thus, the expression "18 inches of vacuum" means that the column has fallen 18 inches, and therefore stands only 30 − 18 = 12 inches high. For 28 inches of vacuum, the column stands 30 − 28 = 2 inches high.

The usual method of measuring a vacuum, however, is by means of a **vacuum gauge**, the principle of operation of which is the same as that of the steam gauge. When the gauge hand points to the figure 5 of the dial, it indicates 5 inches of vacuum, and so on for the other figures on the dial.

SAFETY VALVES

15. Boilers are provided with safety valves in order that the pressure may be relieved in case it rises above the standard amount. Locomotives are provided with two, and sometimes three, safety valves, so that in the event of one becoming inoperative the other will take care of the pressure. Ordinarily, these valves are set to blow off at about 3 pounds difference in pressure, and to close after from 3 to 5 pounds reduction. The one set at the lowest pressure blows off first; if the pressure still rises, the second one opens and discharges an additional volume of steam. They close in the reverse order.

*By an *inch of pressure* is meant that pressure which will sustain a column of mercury 1 inch high.

CROSBY VALVE

16. Description.—In the **Crosby safety valve**, Fig. 7, the valve *a a* rests on the two annular flat seats *b b*, *c c*, and is held down against the steam pressure by the spring *d*, the tension of which is regulated by the bolt *e*. The larger of the two seats *c c* is formed on the upper edge of the valve body; the smaller seat *b b* is formed on the upper edge of the cylindrical chamber *f*. This chamber is closed at the

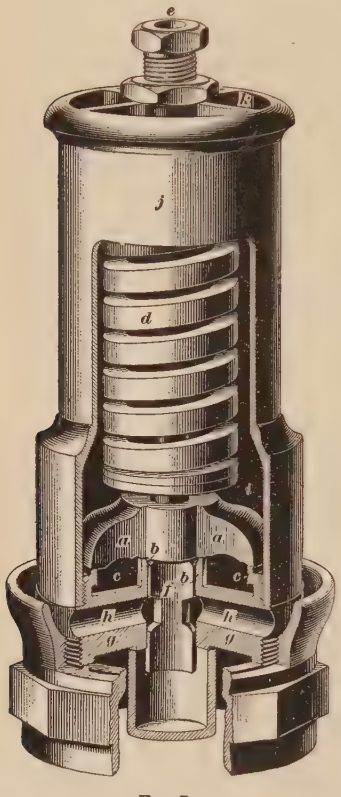


FIG. 7

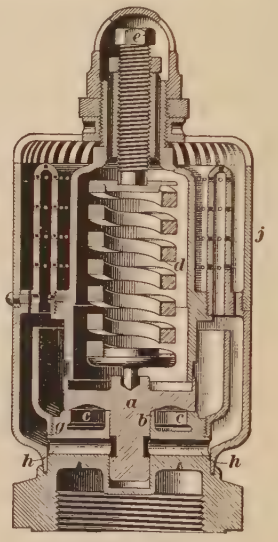


FIG. 8

bottom and connects with the shell or body of the valve by means of the hollow arms *g*, *g*, the passages *h*, *h* allowing the steam to escape to the atmosphere when the valve is open.

17. Action.—When the pressure under that part of valve *a* between the seats *b b* and *c c* is within a pound or so of the maximum allowable pressure, the valve *a* lifts slightly

and allows steam to escape past the seat *c c* into the space *i* inside the casing *j*, and through the holes *k* into the atmosphere. At the same time, steam passes seat *b b* into chamber *f* and thence through the passages *h*, *h* to the atmosphere. As the boiler pressure increases, the valve rises and steam flows into the chamber *f* faster than it can escape through the passages *h*, *h*, the pressure under valve *a* inside the inner seat *b b* thus quickly increases. This additional pressure overcomes the increasing resistance of the spring and forces the valve wide open, quickly relieving the boiler.

In Fig. 8, a **Crosby muffled pop safety valve** is shown with the casing so cut away as to give a sectional view of the interior. The operation of this valve is exactly the same as the one just described, with the exception that this valve has a muffler to make it quiet in discharge. With this valve all the steam must discharge through the top of the valve, and before it escapes it is broken into fine streams that escape without producing the violent noise made by the ordinary pop safety valve.

INJECTORS

PRINCIPLES OF OPERATION

18. General Remarks.—The **injector** is an apparatus for supplying water to steam boilers. It was invented in 1858 by an eminent French scientist, Henri Giffard, and was introduced into this country in 1860 by Wm. Sellers & Co., of Philadelphia, Pa.

On investigating the action of the injector, it will be found that dry steam at a given pressure enters the apparatus, passes through several contracted passages, and forces water past one or more check-valves into the boiler against a pressure equal to or greater than that which it had when beginning the operation. The steam, in forcing the water through the injector and into the boiler, gives up its heat and performs actual mechanical work as truly as though the steam acted

on a piston and moved a pump plunger along with it. A current of any kind—be it steam, air, water, or other fluid—has a tendency to induce a movement, in the same direction, of any body with which it may be in contact. This mechanical principle underlies the action of the injector. The steam, moving with an extremely high velocity, imparts a portion of its velocity to the water, and gives it sufficient momentum to overcome a pressure even higher than the original pressure of the steam. Locomotive blowers, steam jets, siphons, ejectors, etc. are all operated on the same principle of induced flow. The steam enters the injector at a high temperature with a great velocity, and, by striking a cold mass of water, its heat and speed will both be reduced, at the same time condensing the steam. A great portion of the velocity of the steam is imparted to the water, giving the latter sufficient energy to throw open the check-valves and enter the boiler against high pressure.

19. Action of Injector.—The action of an injector can best be explained by referring to Fig. 9, which represents a conventional form. In the figure, *A* is the injector, *B* the boiler, *C* the water supply, *D* the steam pipe to the injector, *E* the water-supply pipe, *F* the delivery pipe, and *G* the boiler check-valve, which is to prevent the water in the boiler flowing back into the injector. In the injector, *S* is the steam valve and *O* the overflow valve, from whence a passage leads to the overflow outlet *x*.

A lifting injector has two functions to perform: (1) it must raise the water from the source of supply *C* into the injector; (2) it must force the water from the injector into the boiler. A non-lifting injector only has to force the water from the injector into the boiler, since it is always located below the water supply and thus is filled with water.

Raising the Water.—To raise the water, the steam valve *S* is opened a small amount; this permits steam to flow out of the steam nozzle *a* into the tube *b*, from whence it passes through the overflow valve *O* and overflow *x* to the atmosphere. The steam flowing through the tube *b* and to the

atmosphere carries with it some of the air from the water-supply pipe *E*, thus creating a partial vacuum there. As soon as sufficient vacuum is formed in the supply pipe, atmospheric pressure, acting on the water in the tank *C*, forces water into the injector, but as the water has not sufficient velocity to

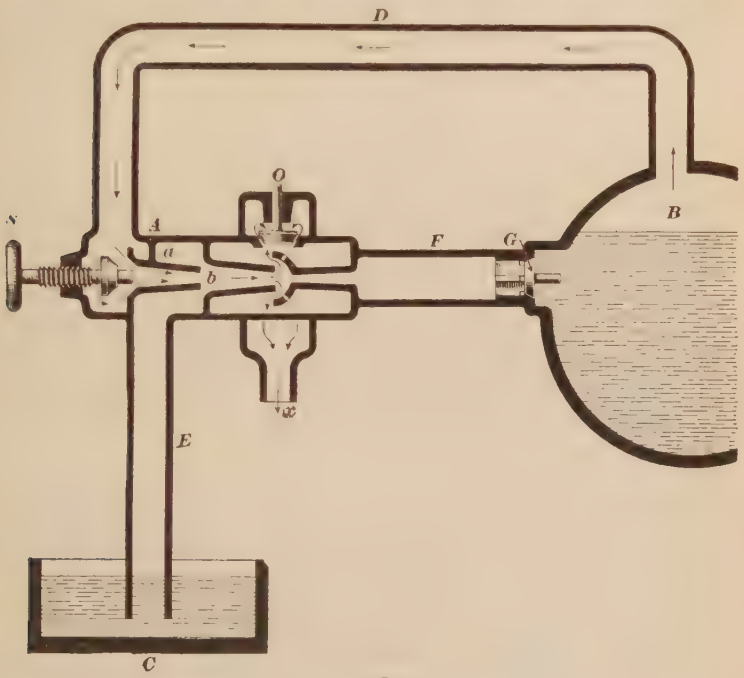


Fig 9.

open the check-valve *G* against the pressure in the boiler, it passes through the overflow valve. The injector is then said to be primed. The action of the steam jet in forming a vacuum in the supply pipe *E* is the same as the action of the blower in creating a vacuum in the smokebox.

Forcing the Water.—When water appears at the overflow of the injector the steam valve is opened wide, which permits steam to pass through the injector in a larger volume. This steam coming in contact with the stream of water that is flowing around the steam nozzle *a* into the tube *b*, forces

the water, with increasing velocity, through the tube *b*. Here the steam is condensed after imparting energy to the feedwater, besides heating it. The steam condensing in tube *b* forms a vacuum of about 24 inches, and it is this vacuum that then acts to raise the water. This vacuum varies with the pressure, being less with high pressures. Since there is a vacuum below the overflow valve *O*, that valve is held on its seat by atmospheric pressure, and as the steam and water discharge into about 24 inches of vacuum, they enter the injector at an increased velocity, which results in a slightly greater final velocity of the water, which soon is sufficient to force the water into the boiler.

In starting an injector, the water enters it at such a low velocity that the water is unable to open the boiler check-valve, so it passes out of the overflow valve to the atmosphere. The water continues to flow out of the overflow until the steam has imparted sufficient velocity to the inflowing water to enable it to "form a jet" and force its way into the boiler.

20. Temperature of Water Delivered.—The temperature at which water will be delivered to the boiler depends on the steam pressure, and on the quantity of water being delivered per pound of steam, the feedwater temperature remaining constant. Thus, if an injector is worked at its maximum capacity of both steam and water, with a steam pressure of 30 pounds, the temperature of the water delivered to the boiler will be about 114° F.; if the pressure is 200 pounds, the temperature of the injected water will be about 154° F. The temperature of the water delivered will increase as the capacity of the injector is cut down from its maximum to its minimum by reducing the water supply. Thus, under 140 pounds steam pressure, and working at its maximum capacity, an injector may deliver water at about 135° F.; while, if the supply of water to the injector is cut down to its minimum capacity, the water will be delivered at about 250° F. If, on the other hand, the steam supply is cut down and the water supply as much as the steam can

handle, the temperature of the injected water will fall. Ordinarily, the water is probably delivered at a temperature between 160° and 200° F.

The highest temperature at which an injector will lift the feedwater and operate without waste decreases as the steam pressure is increased. At low steam pressures, the injector may operate with water at 125° or 130° F., while at 140 pounds and upwards, it is not safe to heat the water much above 110° F.

The number of pounds of water delivered per pound of steam decreases as the steam pressure is increased. At 30 pounds pressure, an injector may deliver 20 to 25 pounds of water per pound of steam, while at 140 pounds, it will deliver only about 13 pounds, and at 180, only about 11 pounds.

21. Classes of Injectors.—Injectors are divided into two classes: *non-lifting* and *lifting*. **Non-lifting injectors** do not raise water, so they must be placed below the level of the water supply. **Lifting injectors** both raise the water and force it into the boiler. They should be located with the overflow opening above the level of the water in the tank when it is full, to prevent water from wasting from the overflow when the injector is not being operated. When located any higher than necessary, they have to lift the water this extra distance, which means a loss of energy. Lifting injectors are of two types, called automatic and positive injectors. The *automatic injectors* are so called because they automatically start again in case they break while working, if conditions are such as to permit of the injector starting. *Positive injectors* are chiefly of the double-tube type, have a closed overflow, and therefore must be restarted by hand in the event of their breaking. This type of injector has a wider range than the automatic, will handle a hotter feedwater supply, and will lift water to a greater vertical height.

The majority of non-lifting injectors are not provided with what is called a priming jet, but simply with a forcing jet that drives the water into the boiler, it having flowed into the injector by gravity. The point of overflow is usually at the level of the injector body, and the overflow valve

must be closed when the injector is not working. Sometimes the injector is provided with a combined overflow valve and heater cock, Fig. 10, connected by a pipe with the overflow space in the injector body, and placed in the cab within convenient reach of the engineer or fireman.

NATHAN NON-LIFTING INJECTOR

22. Description.—Fig. 10 illustrates a form of non-lifting injector; it is known as the **Nathan M** type. It is provided with a water-regulating valve, and also has a priming jet and a steam valve within the body of the injector itself. The injector overflow valve is not contained within the body of the injector, but is usually placed in a convenient position inside the engine cab, and high enough so as to be above the highest level of the water in the tender. It is connected with the overflow chamber in the injector body by means of a pipe. By placing the overflow valve in the cab, above the highest level of the water in the tender, it is under the direct observation of the enginemen, who can then see whether the injector is wasting water at the overflow, and easily open or close it at will; loss of water is prevented while the injector is not working, and the overflow valve need not be closed unless the injector is used as a heater.

In the following illustrations of the various types of injectors, certain parts (the check-valve, overflow valve, etc.) that are common to all will be denoted by the same numerals or letters throughout. Referring to Fig. 10, *1* is the body of the injector; *2*, the yoke; *3*, the priming valve and nozzle; *4*, the steam valve; *5*, the steam nozzle; *6*, the intermediate nozzle; *7*, the condensing nozzle; *8*, the delivery nozzle; *9*, the drain plug, usually a petcock; *10*, the line check-valve, and *11* its cap; *12*, the overflow valve; *13*, the overflow-valve handle; *14*, the water valve; and *N*, the overflow nozzle.

The water connection is made at *W*; the steam connection at *S*. *B* is the delivery pipe; *H*, the handle for regulating the steam supply; and *I*, the handle for the water supply.

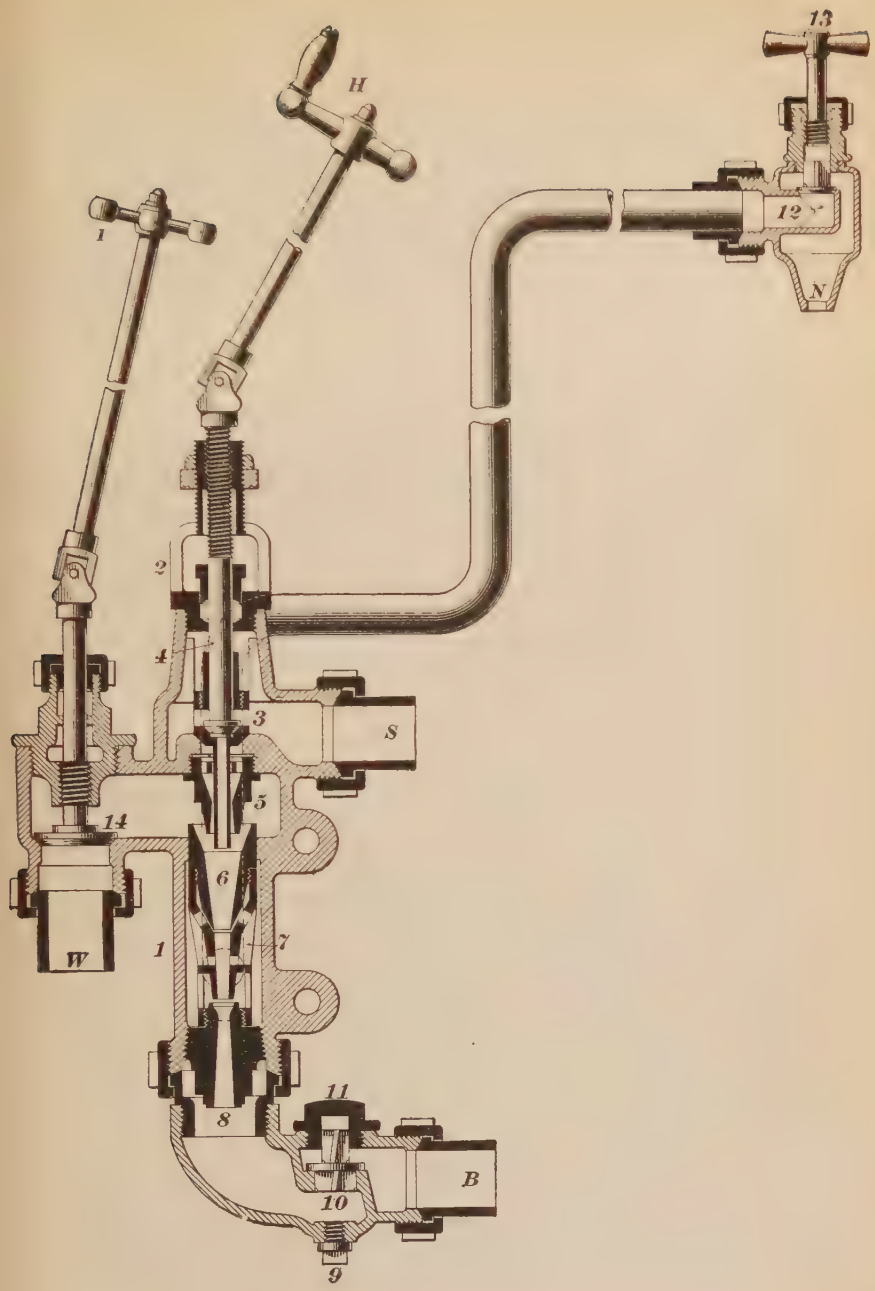


FIG. 10

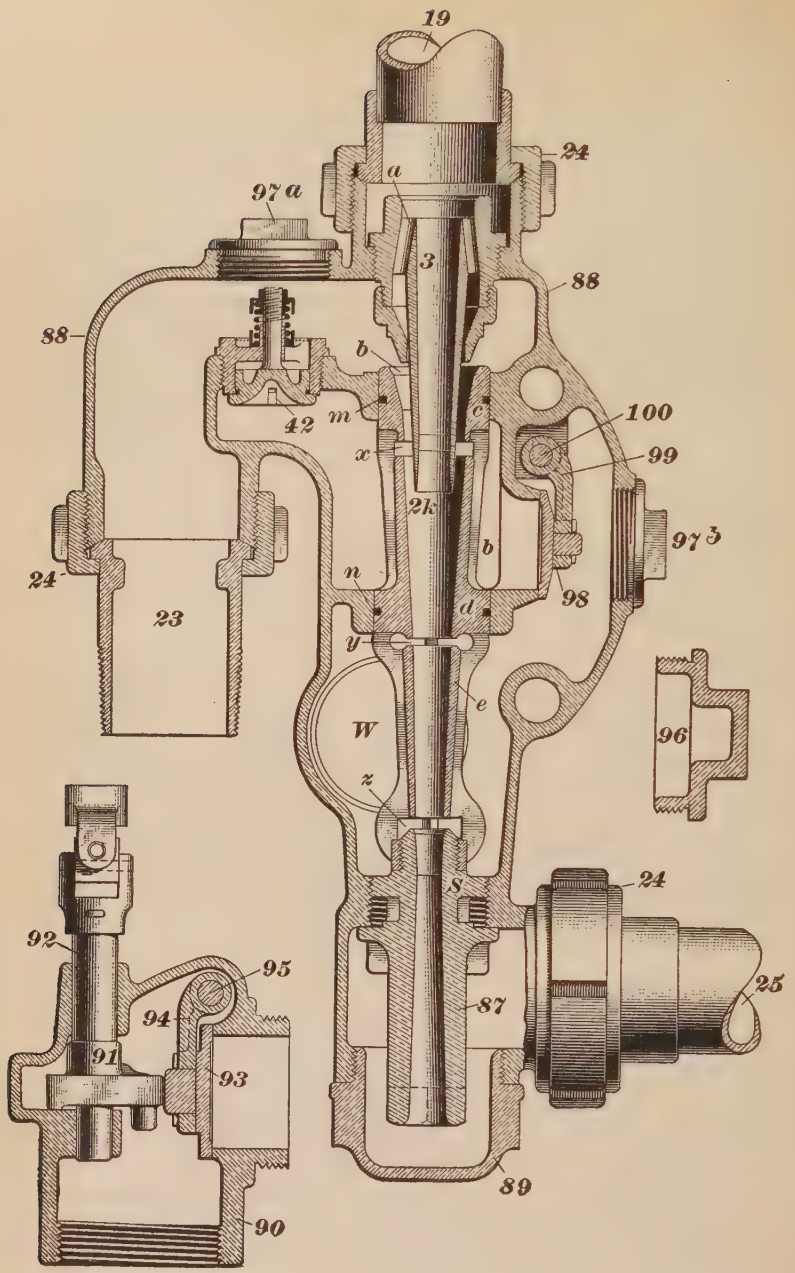
23. Method of Working.—When first starting this injector, see that the tank valve is wide open and then open the water valve *14* by means of the extension handle in cab. Open this valve about one full turn, and then the steam valve *4* a quarter-turn; this will raise the steam valve off its seat in the priming valve *3* and allow steam to pass into the priming valve through holes here shown, and then through the nozzle of the priming valve. The steam, as it issues from the priming nozzle, is condensed by the incoming water, imparting to the latter sufficient velocity to carry the stream of water and condensed steam through nozzles *6* and *7* and out through overflow pipe (shown dotted) and so up to and out the overflow valve *12*. As soon as water appears at the overflow, open the steam valve *4* still wider, which will lift the priming valve *3* off its seat and allow steam to pass through the large opening thus made, and down through the steam nozzle *5*. This will give the water a still greater velocity, enabling it to raise the check-valve *10* and pass into the boiler. Regulate the quantity of water supplied by means of water valve *14*.

To stop the injector, close the steam valve, leaving the water valve as it is—ready for the next starting up of the injector. This will keep the injector body full of water and prevent scale accumulating on the nozzles.

To use as a heater, close the overflow valve *12* by turning handle *13* to the right, and then open the steam valve slightly. At all other times, handle *13* should be wide open. The plug *9* may be replaced by a drain cock, for the purpose of keeping the injector and overflow pipe free of water when not in service; in such a case, the tank valve must be kept closed. In the event of a leaky boiler check, this drain cock should be left open, as the hot water will thus drain away and keep the injector cool.

SELLERS NON-LIFTING SELF-ACTING INJECTOR, CLASS K

24. Description.—The **automatic non-lifting injector** is illustrated in Fig. 11. *3* is the steam nozzle, which consists of two parts, one part having a large central opening and the other part forming a sort of sleeve or annular opening around the central tube at *b*. A number of small holes *a* are drilled in the tube *3* to admit steam to this annular opening *b*, from which the steam passes through the first section *c* of the complete combining tube *2k*. This arrangement aids in restarting when the supply of water is shut off momentarily. *87* is the delivery tube; it is fastened to the combining tube by brackets across the spill opening at *z*. The various sections of *c*, *d*, and *e* of the combining tube are also fastened together by brackets across the spill openings at *x* and *y*, so that the combining and delivery tubes are fastened together in one complete set of tubes, which can be taken out or replaced in the body of the injector at one operation. The delivery tube *87* is screwed into the body of the injector to make a solid joint at *S*. Where the combining tube *2k* passes through the division walls of the injector body, small packing grooves at *m* and *n* are provided, in which packing is inserted so as to make these joints water-tight. *89* is a cap nut that is removed when necessary to take out the combining and delivery tube. *90* is the waste-valve body, which is screwed into the body of the injector at *W*. To make the waste valve either right- or left-handed, there is an opening for it on each side of the injector; the one not used is closed by the cap *96*. *93* is the waste valve, which swings on a hinge *94*. *91* is a cam to close the waste valve when necessary. This cam is operated by the cam-shaft *92*. An extension of this cam-shaft runs up into the cab, convenient for the engineer to open and close the valve *93*. A type of waste or overflow valve that can be closed by a screw motion instead of a cam is now supplied in place of the cam motion, as shown in Fig. 12. *42* is the inlet valve, which opens downwards and is held to its seat by a spring of considerable tension. This valve is intended to admit water from the


19
24
97a
a
3
88
88
b
42
m
c
100
x
99
21k
97 3
24
23
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d
y
e
W
96
z
S
24
92
95
25
94
87
91
93
89
90

Fig. 11

feedpipe *23* into the space around the combining tube *24* and pass into the tube at the spill openings *x*, *y*, and *z* at any time when the steam can force more water than will pass through the draft tube *c*. The purpose of the inlet valve *42* is to admit water supply only when there is a vacuum in the overflow chamber. Therefore, a stiff spring is placed on this valve so that it will be held closed under the full head of water in the tender when the injector is not working or unless there is a vacuum in the overflow chamber. Another type of inlet valve is shown in Fig. 12. *97ª*, Fig. 11, is a cap nut that can be removed when necessary to get at the inlet valve *42*. A similar cap nut *97ᵇ* is used over the hot-water valve *98*. These cap nuts are interchangeable. *98* is the hot-water valve, which swings on its hinge *99*. Pins at *95* and *100* pass through the hinges of these swing valves and keep the valves in position; the valves also have a little lateral motion on their hinges so that they will seat tight.

25. Operation.—The feedpipe is connected at *23*, the supply of steam from the boiler enters at *19*, and the water passes from the injector to the delivery pipe at *24*. Open the overflow and water-regulating valves, then the steam valve, and supply just enough steam to pick up all the water at the overflow. Regulate the supply of water desired by the water valve. After the injector is once started with the proper regulation of steam and water supply, it is "self-adjusting"; that is, it will not waste water at the overflow when the steam pressure drops.

If the feedwater is above 105°, close the overflow valve after the injector has started. This prevents the escape of the water, which would ordinarily come out at the spill openings and raise the pressure in the overflow chamber around section *e* of the combining tube until the pressure will hold the hot water valve *98* on its seat and force the hot feedwater, which would otherwise pass out through the spill opening at *x*, to pass through *d* and on into the boiler.

When an injector is working with a high steam pressure, after the jet is formed and all the water that can pass

through the draft tube *c* is passing into the boiler, the stream passing through the tube and across the openings *x*, *y*, and *z* will take in more water, which passes through the delivery tube and into the boiler. This produces a partial vacuum in the overflow chamber around the tube; the inlet valve *42* will open against the tension of its spring; feedwater will pass into the overflow chamber, thence into the combining tube. Therefore, the water coming through the inlet valve *42* will pass into the delivery tube and increase the capacity of the injector about 20 per cent.

Tests made with this type of injector show that it will restart when the water supply is temporarily interrupted with feedwater at a temperature of 135° with a working steam pressure of 60 pounds. With 120 pounds of steam, the temperature of feedwater can be 122°; at 180 pounds, 112°; at 200 pounds, 106°. With a closed overflow, the breaking temperature for 60-pound steam is 145°; with 120-pound steam, it is 150°; with 150-pound steam, it is 151°; with 180-pound steam, it is 150°; and with 200-pound steam, it is 147°.

26. Automatic Water-Supply Valve.—With the older types of non-lifting injectors it was necessary to open the lazy cock or water-regulating valve and the overflow valve, to allow the feedwater to flow through the injector; then admit steam gradually to start the stream of water rapidly through the tubes, and afterwards admit steam enough to give it the high velocity necessary to make it pass into the boiler. This not only took the engineer's attention from the signals and track but caused a great waste of water. To avoid the necessity of opening and shutting a water valve each time the injector is started and stopped, William Sellers & Co., Inc., manufacture a water-regulating valve that opens automatically when steam is turned into the injector and closes when steam is shut off. This device not only makes the operation of a non-lifter safer and more convenient for the engineer, but more economical with feedwater, as none is wasted at the overflow when starting or

stopping the injector. The first form of valve manufactured was located on the water-supply pipe close to the injector, and a small steam pipe connected it with the injector steam-supply pipe. This device has been improved and incorporated in the body of the injector and is shown in its present form in Fig. 12. With this automatic water valve it is not necessary to watch the overflow, as no water will waste when the injector is shut off.

IMPROVED N-L INJECTOR

27. Description.—The sectional view of the **improved N-L injector** shown in Fig. 12 illustrates how the parts appear when in operation with the automatic water valve *236* in open position. Steam from the steam pipe *19c* flows down through the passage in the body of the injector into the cap nut *238* and under piston *237*, forcing the piston up and raising the automatic valve *236* into the recess in the bottom of the lazy cock *234*. This recess is deep enough to permit the lazy cock to be opened or shut without interfering with the action of the water valve *236*. Water then passes valve *236* in a full volume into the draft section *c* of the combining tube *2*, where the steam jet from the steam nozzle will start the water through the combining tube, and as the steam valve in the cab can and should be quickly opened, the combined jet of water and steam is formed and at once goes to the boiler through delivery tube *87* and the delivery pipe *23a*. The steam nozzle, and combining and delivery tubes have the same interior construction as those in Fig. 11 and do not need any additional description here. These tubes are the proper design to make the injector self-adjusting, requiring no regulation of the water supply to prevent waste at the overflow when the steam pressure falls; it is also restarting or automatic. The valve *98* and the partition across the injector body at *d*, shown in Fig. 11, are not included in the design shown in Fig. 12.

When the full steam pressure necessary to operate the injector is flowing into the tubes, the action of the combined

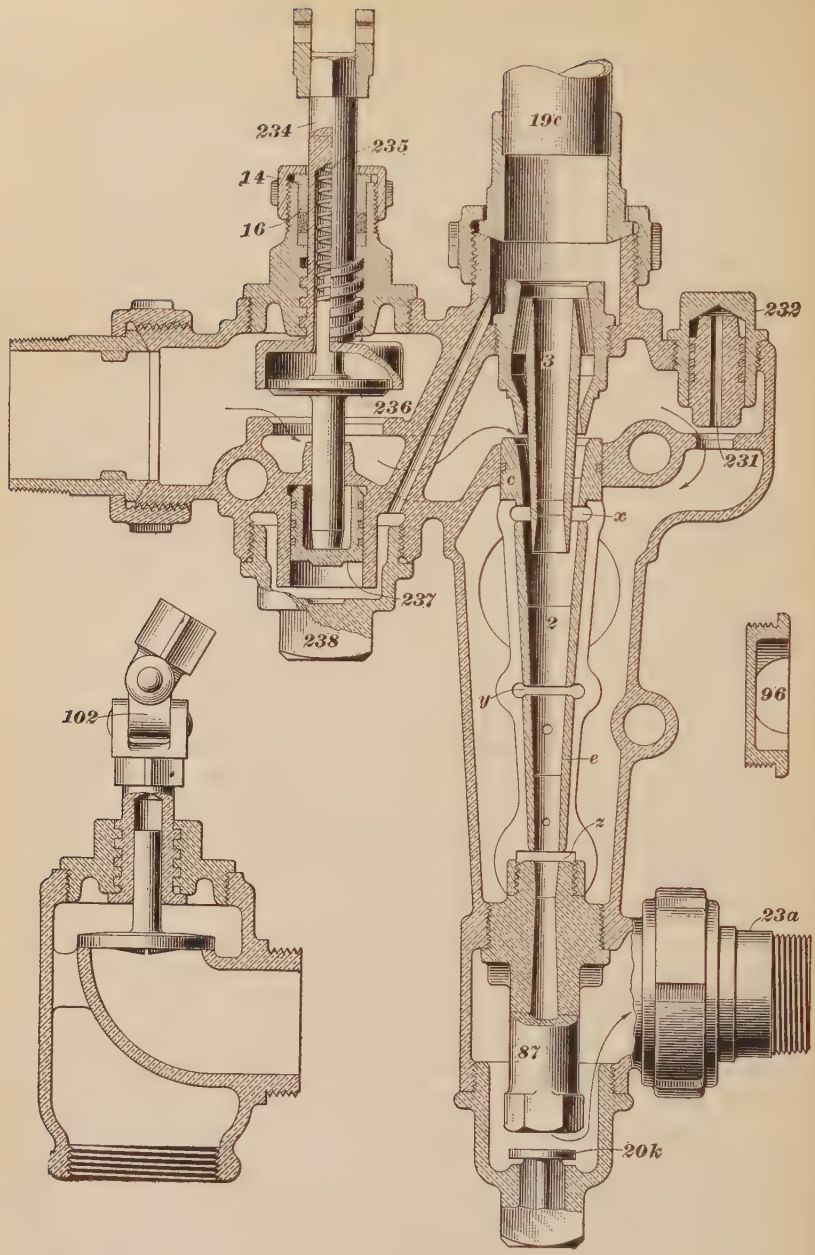

FIG. 12

jet of steam and water when passing the spill openings at *x*, *y*, and *z*, and at the small holes drilled in the lower section *e* of the combining tube is such as to produce a partial vacuum in the body of the injector around the combining tube. This vacuum is also in the cap nut *232*, the connection with the overflow chamber being the hole drilled through the inlet valve *231*. With a partial vacuum above valve *231* and a water pressure around this valve, it rises as shown in Fig. 12; feedwater then flows into the overflow chamber, around the combining tube and into the spill openings, joining with the stream passing through the tubes, thus increasing the capacity of the injector. This action of the inlet valve takes place only above 160 pounds pressure with a full supply of steam, which requires a greater supply of water than will pass through the draft tube *c*. At the lower steam pressures, inlet valve *231* is on its seat; also when the injector is being started or when restarting.

At the bottom of the delivery tube *87* is a line check-valve *20k* that opens when the jet of water passes through the delivery tube and closes when the flow of water is in the other direction, to prevent emptying the delivery pipe. This valve is to supplement the regular boiler check-valve.

When the supply of steam is shut off at the steam valve in the cab, the pressure in the cap nut *238* under piston *237* also drops, so the piston and valve are moved down by gravity, assisted by the spring *235*. This entirely stops the flow of water from the tank.

There is no escape of steam around piston *237* when the injector is working, for the top edge of the piston makes a steam-tight joint where it touches the injector body. The water packing grooves in the side of the piston make it so nearly steam-tight that very little steam can leak by them. This insures that it will rise with a low steam pressure.

The lazy cock *234* has a quick-thread screw on its stem and a packing gland *16* with its nut *14* to make it water-tight. By means of the quick-thread screw and a rod reaching up into the cab the valve is easily operated by the engineer. It

is not necessary to move this valve except to regulate the supply of water when the injector is working.

The overflow or waste valve is also shown in section; its construction needs no explanation. A rod extends from the universal joint *102* up into the cab. It can thus be operated by the engineer in case it has to be closed when using boiler steam to heat the water in the tank, or when using very hot feedwater. When steam is passing from the injector back into the tank, valve *236* will rise off its seat but does not obstruct the passage.

This overflow valve is located near the top of the injector body. This allows the tubes to be covered with water when not in operation. They do not scale up so quickly as those of a lifting injector located above the water-line of the tank where the tubes are exposed to steam only when not operating.

The overflow valve can be attached to either side of the injector body. It will thus fit either side of the locomotive. The side cap nut *96* is used to close the opening not used for the overflow valve. The operation of this injector to handle hot water is the same as that previously described.

To use the injector as a heater, close the overflow valve, open the water valve, and regulate the amount of steam supplied by adjusting the steam valve.

LIFTING INJECTORS

28. Every lifting injector consists of a lifting apparatus for raising the water, and a forcing apparatus for delivering the water to the boiler. To perform both functions, the injector must contain: (1) a steam nozzle, through which the steam from the boiler enters the injector; (2) a lifting tube, by means of which a vacuum is formed in the suction pipe and the water raised; (3) a combining-and-condensing tube, in which the steam and water meet, and the steam is condensed and transmits its energy to the stream of water; and (4) a delivery tube, in which the water attains its maximum velocity. These are considered the essential parts

of a lifting injector. In some injectors, the lifting and the combining tubes are separate, while in others they are combined and form one tube, which is called the combining or condensing tube.

A number of makes of lifting injectors, all operating on the same principle, are used on locomotives, the *Ohio*, *Sellers*, *Monitor*, *Simplex*, and *Metropolitan* injectors being some of the principal ones. Some locomotives are equipped with the *inspirator*, an instrument that performs the same functions as a lifting injector.

OHIO INJECTOR

29. Description.—The **Ohio injector** is shown in cross-section in Fig. 13, in which *1* is the back part, and *2* the front part, of the body of the injector; *3*, the delivery-end connection; *4*, the primer; *5*, the steam valve; *6*, the steam nozzle; *7*, the lifting tube; *8*, the combining tube; *9*, the delivery tube; *10*, the line check-valve; *11*, the stop-ring for limiting the travel of the check-valve; *12*, the overflow valve; *13*, the overflow-valve handle; *14*, the water valve; and *N*, the overflow nozzle. The steam pipe to the injector is connected at *S*, the water-supply pipe at *W*, and the pipe that delivers the water to the boiler at *B*. The overflow chamber *d* is connected with the overflow nozzle *N* by a passageway in the body of the injector, as shown dotted. A waste pipe with a funnel on the end is brought up under the nozzle *N*, and carries away the waste water from the overflow.

30. Method of Working.—To start the injector, open water valve *14*, pull back the lever *H* far enough to just open the steam valve *5* slightly, and, when water appears at the overflow, pull back the lever as far as it will go. To stop the injector, close steam valve *5* by pushing the lever forwards. Regulate the water supply by means of the water valve *14*.

When steam valve *5* is opened slightly in starting the injector, steam flows into the primer *4* through four small holes *a*, expands and pushes the primer forwards until it rests on its seat in steam nozzle *6*. The steam then flows through

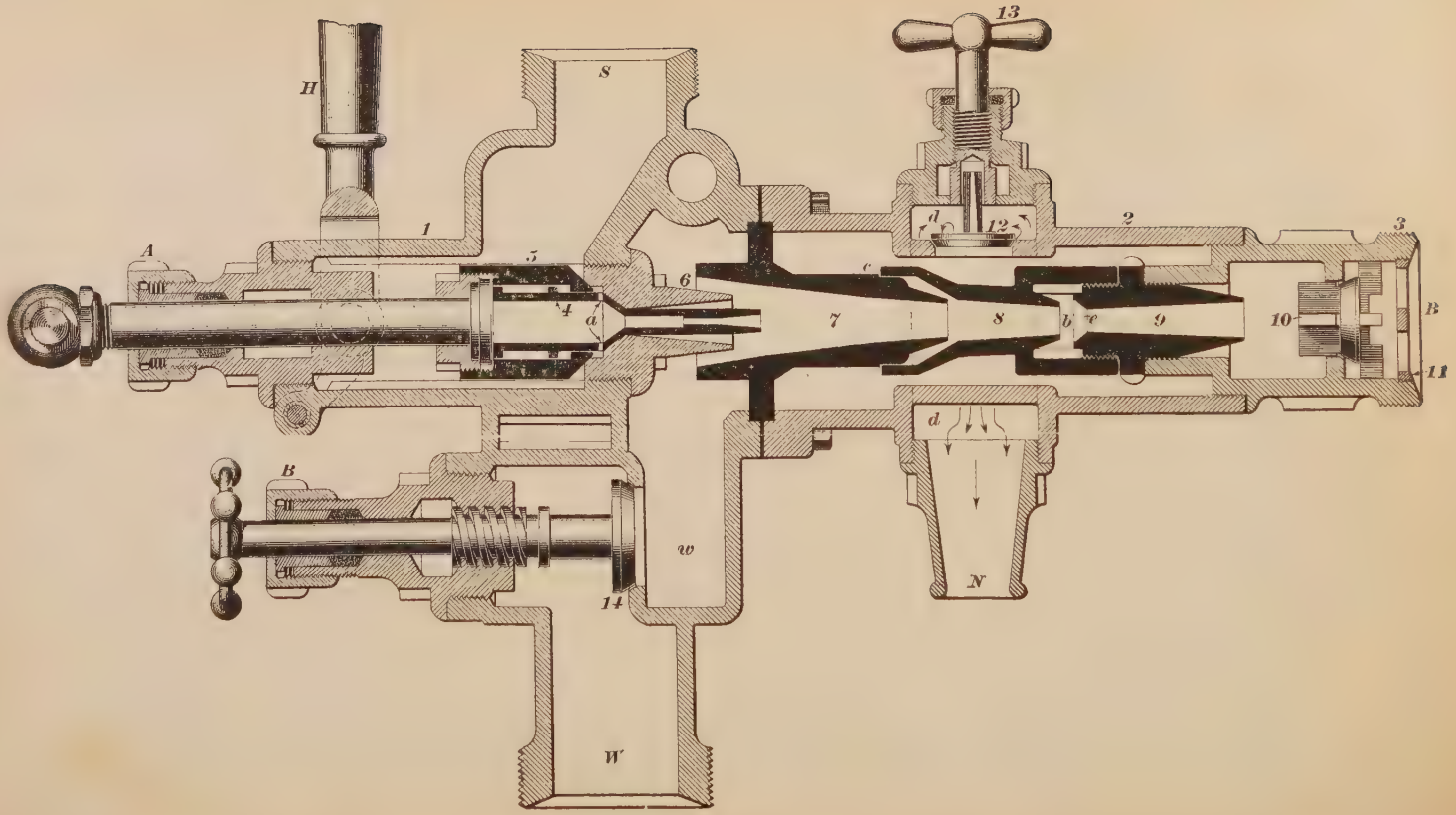

Fig. 13

the primer *1* into the lifting tube *7*, where it expands, filling the tube and creating a partial vacuum in chamber *w* and supply pipe *W* by carrying the air with it as it passes through the tube and out of the overflow. As soon as sufficient vacuum is formed in the supply pipe, atmospheric pressure, acting on the water in the tank, forces water into the injector; but as the water lacks sufficient velocity to open the boiler check-valve against boiler pressure, it passes through the overflow. The steam valve *5* is then opened wide, which withdraws the primer from its seat and permits steam to issue in much larger volume through the large orifice of the steam nozzle *6*. The steam then comes in contact with the annular stream of water that is flowing around the steam nozzle *6* into the lifting tube, the water is forced along with increasing velocity by the steam, and the water and steam enter the combining tube *8* together, where the steam is condensed, forming a vacuum there and giving up its heat and imparting more energy to the feedwater. As the steam condenses in the combining tube, it forms a vacuum of about 24 inches, and it is this vacuum that then acts to raise the water. The overflow valve is now held on its seat by atmospheric pressure, and, as the steam is discharging into about 24 inches of vacuum, it enters the injector at an increased velocity, which results in a slightly greater final velocity of the water. The shape of the tubes also tends to increase the velocity of the water.

In starting the injector the water enters the injector at such a low velocity that it is unable to open the boiler check-valve; so it passes out of the combining tube through openings (or spills) *b* and annular space *c*, thence through the overflow valve *12* and the overflow nozzle *N*. This continues until the steam has imparted sufficient velocity to the inflowing water to enable it to form the jet and force its way into the boiler. This action may be quickened by slightly closing the water valve *14* until the jet is formed, when it may be opened the proper amount for regulating the supply of water.

To use as a heater, close the overflow valve *12* by means of handle *13*. To get the amount of steam desired, adjust the injector steam throttle on the boiler and pull the handle *H*

back as far as it will go, to open steam valve *5*; steam will then enter the injector, and force its way into the tank, if the water valve *14* is open. The overflow valve of a single-tube injector should be left open, except when the injector is being used as a heater.

31. Tubes.—Both the lifting and the combining tubes are bored out tapering, and placed with their smaller end toward the delivery tube. The delivery tube is also bored out tapering, but its small end *e* is placed next to the condensing tube. Now, the same quantity of water that flows through the large end of the tube *7* in a unit of time must flow through the small end *e* of the delivery tube in the same length of time. To do this, the velocity of the water as it passes through *e* must be considerably greater than when it was flowing through tube *7*. A common example of this principle is to be seen in a running stream of water; where the stream is wide, the current or flow may be slow and sluggish; where the stream is narrow, the water flows faster, and rapids are formed. The same quantity of water that flows into the wide part of the stream flows through the narrow part, for, if it did not, the narrows would act as a dam and raise the level of the water.

32. Capacity.—The capacity of an injector depends mainly on the diameter *e* of the delivery tube; the distinguishing number of the injector expresses the size of this diameter, usually in millimeters. Thus, in a No. 6 injector the diameter *e* would be 6 millimeters, while in a No. 9 injector it would be 9 millimeters. A millimeter is .03937 inch, or nearly $\frac{1}{25}$ inch, in length.

SELLERS INJECTOR

33. Description.—A sectional view of the **Sellers injector** is given in Fig. 14, in which *1* is the delivery tube; *2*, the combining tube; *3*, the steam nozzle; and *4*, the primer or lifter steam nozzle. Steam connection is made at *S*, and water connection at *W*, *B* being the delivery pipe to the boiler.

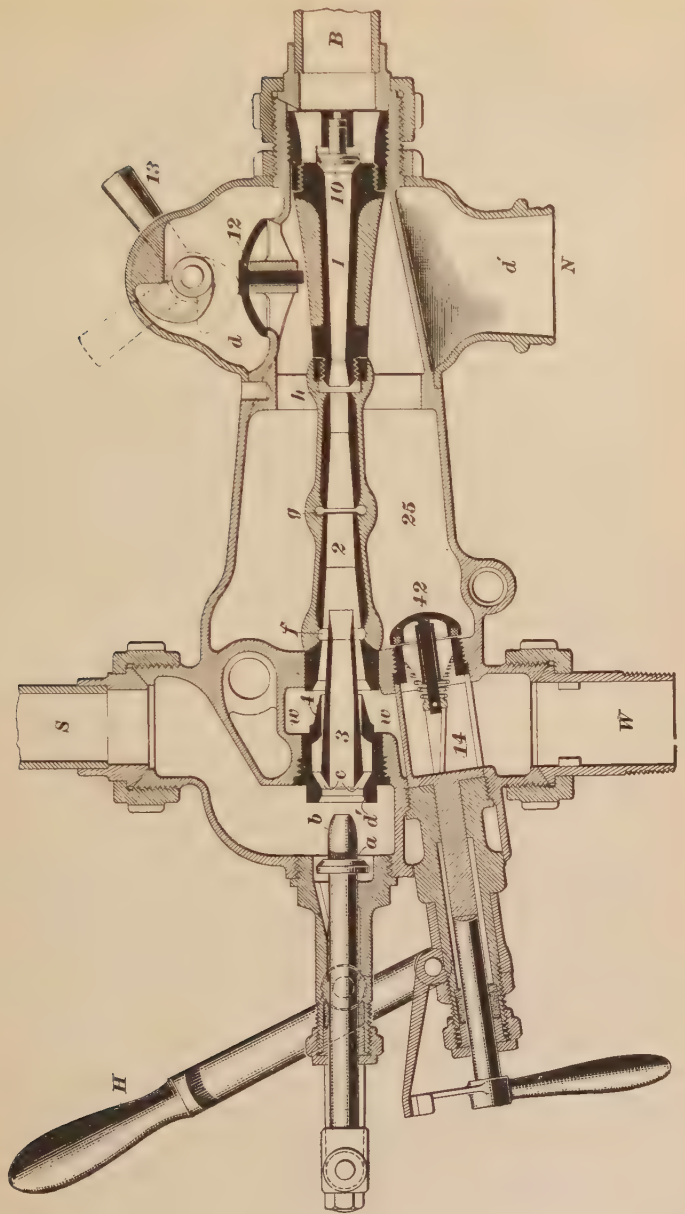

FIG. 14

34. Method of Working.—To start the injector, the lever *H* is pulled backwards sufficiently to move valve *a* from its seat *a'*. This permits steam to flow into the lifter steam nozzle through the openings *c*, but the stem *b* still closes the end of the steam nozzle *3* and prevents steam from flowing through it. After issuing from the primer *1*, the steam enters the combining tube *2*, and escapes from the tubes through the openings *f*, *g*, and *h*. It then passes through the overflow valve *12* into chamber *d*, and thence through a passageway into *d'* and out at the overflow *N*, creating a vacuum in the water-supply pipe *W*, which causes the water to rise into the injector and pass out of the overflow. The lever *H* is then drawn all the way back, thus withdrawing the stem *b* from the steam nozzle *3*. This allows a larger volume of steam to pass through the steam nozzle into the combining tube, where it comes in contact with the water, to which it imparts its heat, and by which it is condensed; it at the same time imparts sufficient velocity to the water to enable it to open the check-valve *10* and the boiler check, and feed into the boiler. If, for any reason, the injector breaks, the steam issuing from the steam nozzle *3* will escape so freely through the openings *f*, *g*, and *h* as not to seriously interfere with the operation of the lifter steam nozzle *4*, which, consequently, tends to maintain a vacuum in the water-supply pipe; thus the injector will again lift and force the water into the boiler as soon as the cause of its breaking is removed. This is, therefore, a restarting injector. The primer *4* not only lifts the water and maintains the retarding feature, but also forces a continuous jet of water into the combining tube *2* when the injector is feeding, thus producing a jet of water and condensed steam, which is continuously and evenly accelerated from the instant it enters the mouth of the combining tube until it reaches the minimum diameter of the delivery tube.

To use as a heater, close the overflow valve *12* by turning up the lever *13*, as shown in dotted lines in Fig. 14, open the water valve *14*, and also the steam valve *a*. Then adjust the injector steam throttle on the boiler, to get the proper amount of steam.

When an injector is working with a high steam pressure after the jet is formed, and all the water that enters the mouth of the combining tube *2* is passing into the boiler, more water can be drawn in through the openings *g* and *h* and pass into the boiler through the delivery tube *1*. The action of the stream of water passing the openings *g* and *h* draws in this water; some is also taken in at *i*, and a vacuum is created in the chamber around the tubes so that the overflow valve is held on its seat by the outside air trying to get into this vacuum. Hence, it follows that if a supply of water can be furnished to this chamber, it will increase the capacity of the injector.

The by-pass valve *42* allows water to flow from the suction pipe *W* into the chamber *25* around the tubes where it passes into the combining tube through the openings *g* and *h*, thus adding to the volume of the water passing into the boiler. This valve *42* is held on its seat by a spring, so that when priming the injector, or in case it breaks, the steam and water will not pass back into the suction pipe. As soon as the injector is working and a vacuum is produced in the chamber *25*, the valve will be lifted from its seat against the tension of the spring.

SCREW MONITOR INJECTOR

35. Description.—A sectional view of the **screw monitor injector** is shown in Fig. 15. With this style of injector, the steam valve *5* is operated by means of a quick-motion screw attachment *H*; the lifting valve *3* by means of the lever handle *J*; and the water valve *14* by the lever handle *23*. This injector has the lifting nozzle *4* above the overflow nozzle *N*, being connected with the lifting valve *3* by the jet tube *T*. The water valve *14* is operated by means of the eccentric spindle on the lever handle *23*.

The port *k* in the condensing tube is for the purpose of giving a freer exhaust in the priming. This port is not so necessary when the injector tubes are free from lime, but after a time the spills begin to lime up and the opening

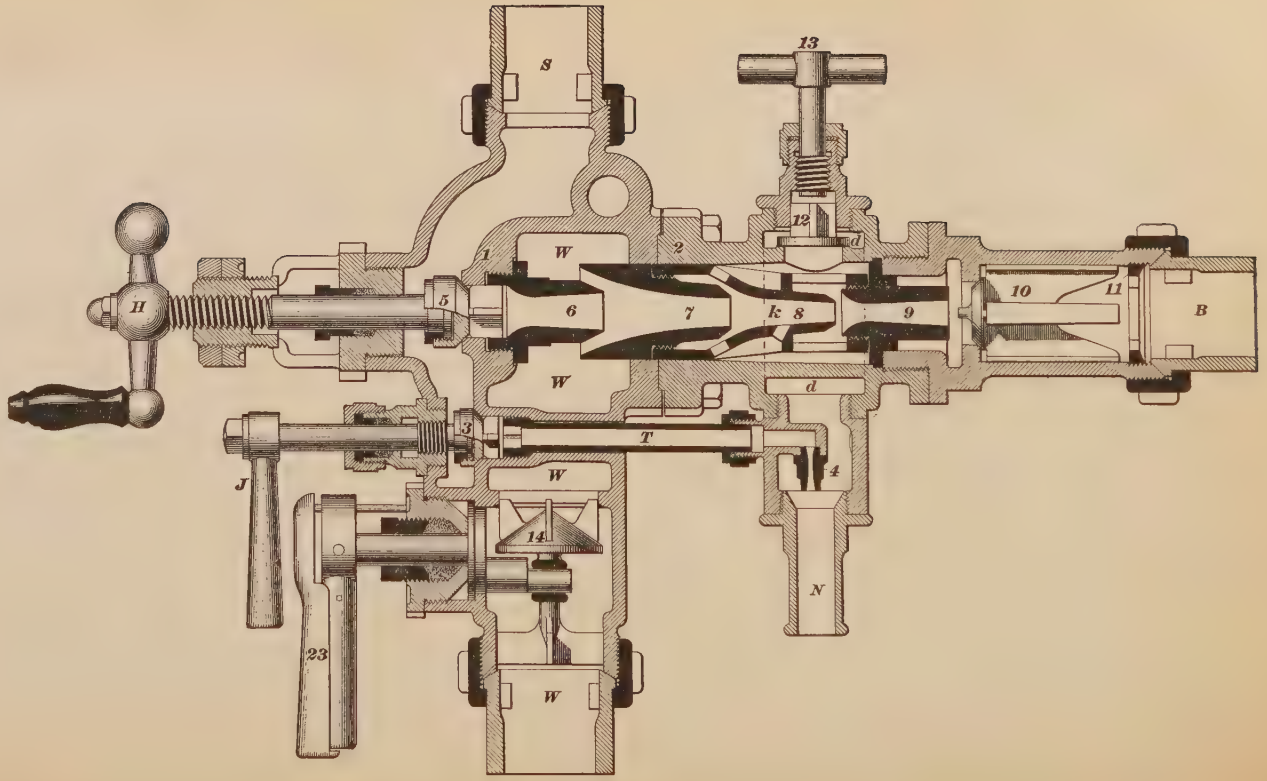

Fig. 15

through them decreases so that the added area of the port *k* is necessary to make the priming of the injector certain. This port should be present in all single-tube lifting injectors.

36. Method of Working. To start the injector, open the lifting valve *3*; when water appears at the overflow, open the steam valve *5* far enough to cause the overflow to cease, then close the lifting valve *3*. The steam supply should not be increased beyond the amount necessary to cause the overflow to cease. When the lifting valve *3* is unseated, steam flows through the jet tube *T* and lifting nozzle *l*, thence through the overflow nozzle *N* to the atmosphere. This produces a vacuum in passage *d* above the overflow valve *12*, causing it to be raised and held off its seat; as soon as the vacuum extends back into the water-supply pipe *W*, water will raise into the injector and pass out at the overflow. The steam valve is then opened far enough to force the water into the boiler and stop the overflow when the lifting valve is closed. To stop the injector, close the steam valve *5*.

To use as a heater, close the overflow valve *12* by screwing down the T handle *13* and open the steam valve *5*; regulate the injector steam throttle to supply the proper amount of steam. The handle *13* should be unscrewed so as to have the overflow valve *12* free except when the injector is being used as a heater.

To grade the injector, reduce the water supply, by means of the water valve *14*; if that is not sufficient, close the steam valve *5* enough to give the desired results.

LEVER MONITOR INJECTOR

37. Description.—In Fig. 16 is illustrated the 1888 type of the **lever monitor injector** in section, showing the arrangement of the nozzles and other parts. *1* and *2* are the front and the back parts, respectively, of the body of the injector; *3*, the lifter valve; *4*, the lifter steam nozzle; *5*, the steam valve; *6*, the steam nozzle; *7*, the lifting tube;

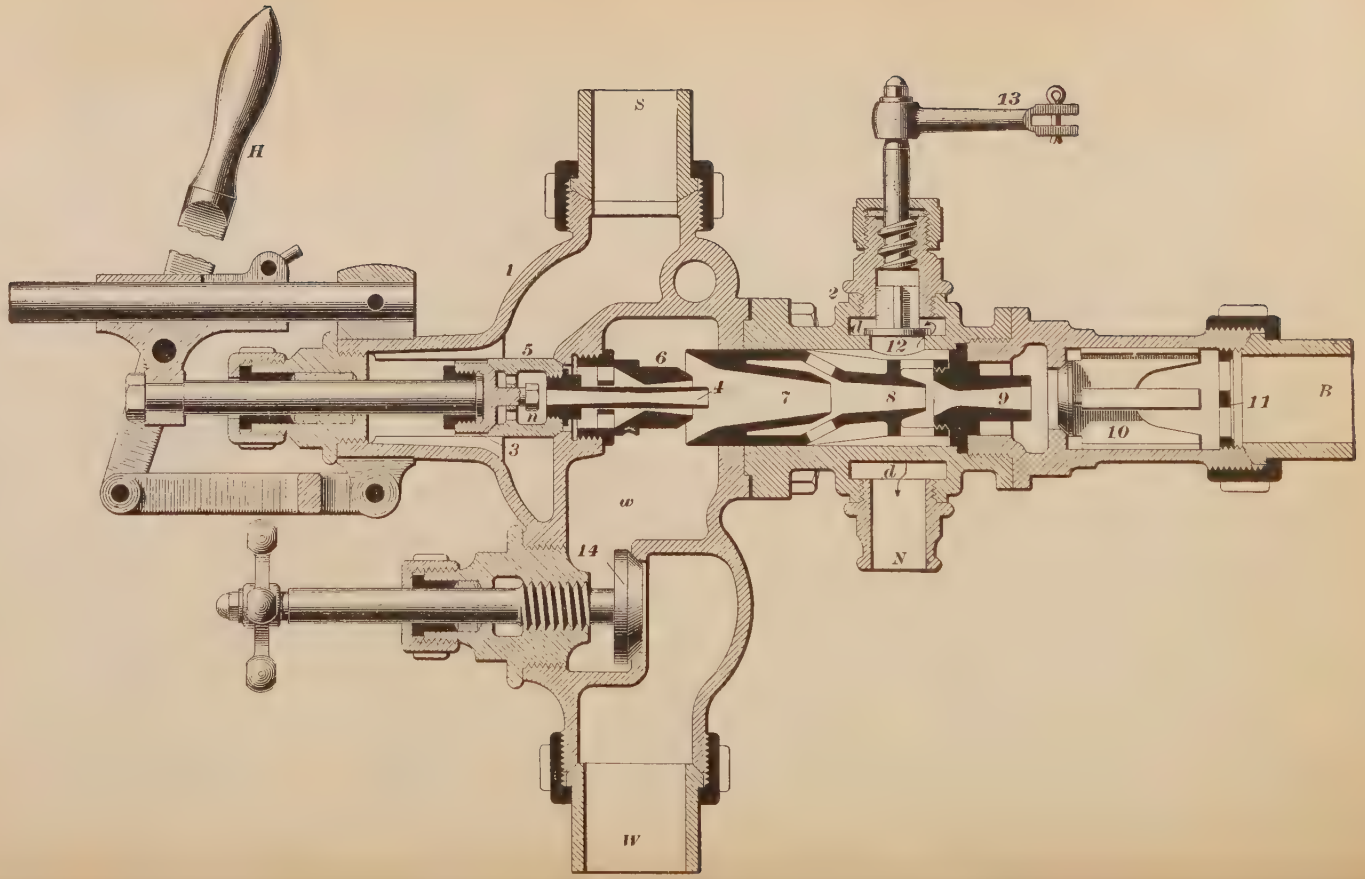

Fig. 16

8, the condensing tube; *9*, the delivery tube; *10*, the line check-valve; *S*, the steam connection; *W*, the water connection; and *B*, the delivery to boiler.

38. Method of Working.—To start the injector, open the water valve *14*, and pull back the lever *H* a short distance to raise the water; after it appears at the overflow *N*, steadily draw back the lever until the overflow ceases. When the lever is first pulled back a little, to raise the water, the lifting valve *3* is unseated, and steam flows through the lifting nozzle *1* and tube *7* and out of the overflow, raising the water into the injector. The lever is then pulled all the way back, which causes the nut *n* to unseat the steam valve *5* and pull back the lifter nozzle *4*. Sufficient steam then enters the tubes through the large steam nozzle *6* to impart the necessary velocity to the water.

To use as a heater, close the overflow valve *12* and open the steam valve *5* and the water valve *14*; regulate the steam supply by adjusting the injector steam throttle on the boiler.

SIMPLEX INJECTOR

39. Description.—An improved type of automatic injector, manufactured by the Nathan Manufacturing Company, is shown in Fig. 17. This injector, called the **Simplex**, is somewhat different in detail from that illustrated in Fig. 16, but it handles the water in practically the same way. It differs in that it has a by-pass from the supply pipe through the inlet valve *19* and emergency valve *35* into the space *25* surrounding the tubes 7, 8, and 9. When the injector is in operation, a vacuum is formed in the chamber *25* and water is forced through the by-pass into the chamber, whence it passes into the tubes through the spills, or openings, and to the boiler, thus adding considerably to the capacity of the injector. The inlet valve *19* is a check-valve, and the cap *18* closes the opening through which valve *19* is put in place. The emergency valve *35* is operated with a wrench, and can be turned so as to close port *p* and block the

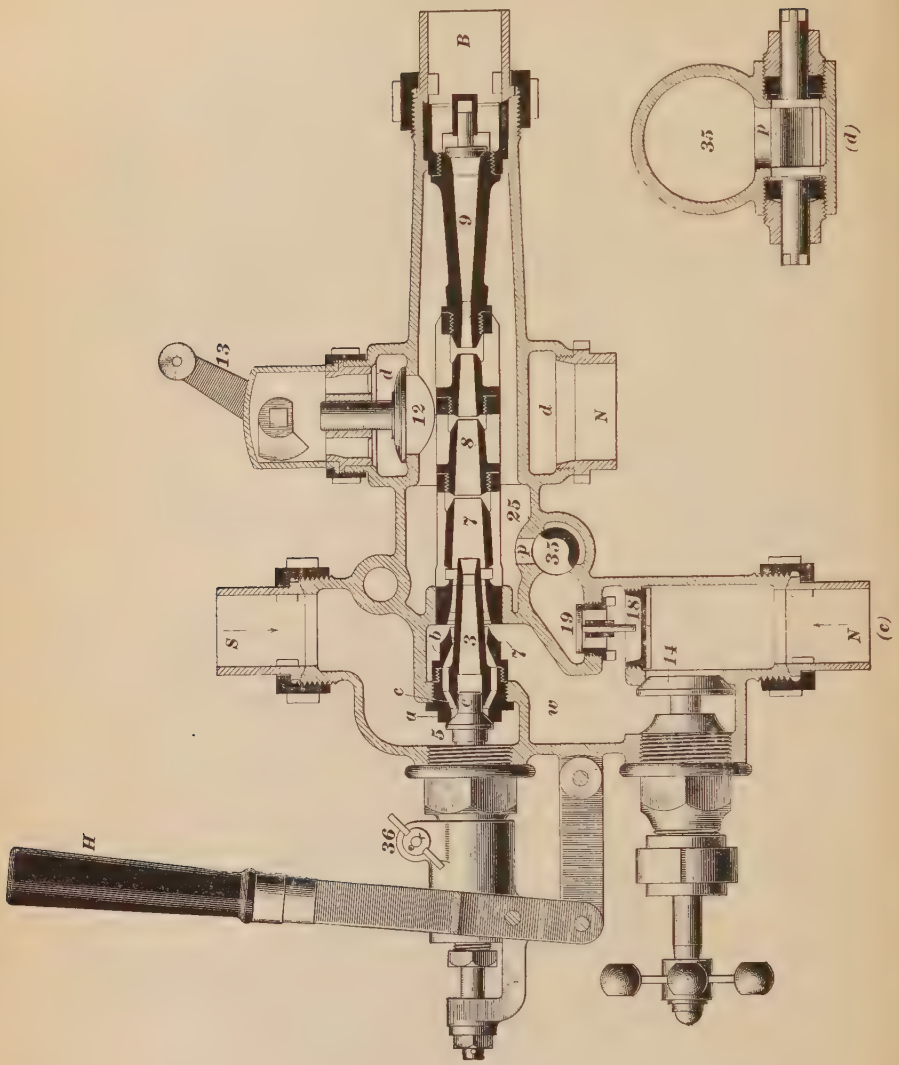

FIG. 12

by-pass in the event of valve *19* leaking or being held from its seat, thus preventing steam and hot water from passing into the suction pipe when the injector is priming or when it breaks. Without this emergency valve the injector can not be worked if the inlet valve *19* happens to leak. When the letter *O* on the stem of valve *35* is on top the valve is open; when *S* is on top it is shut.

40. Method of Working.—To start the injector under ordinary conditions, pull out lever *H*; if starting on a high lift, or when the water in the supply pipe is hot, pull out the lever slowly. Regulate the quantity of water by means of the water valve *14*. This injector is operated exactly like the Sellers injector. To stop the injector, push in lever *H*.

To use as a heater, open water valve *14*, close overflow valve *12* by means of cam-lever *13*, and draw out lever *H*. To hold the steam valve *5* part way open, use clamp screw *36*.

METROPOLITAN INJECTOR

41. Description.—In Fig. 18 is shown a sectional view of the **Metropolitan injector**, a type that differs considerably from the others here shown, it being what is known as a *double-tube injector*. It contains two sets of tubes—a lifting set and a forcing set, the former of which lifts the water through the suction pipe and delivers it under pressure to the forcing set, which forces it into the boiler. In the figure, *1* is the lifting jet; *2*, the lifting combining tube; *3*, the forcing jet; *4*, the forcing combining tube; *5*, the steam valve; *6*, the auxiliary steam valve; *10*, the check-valve, and *11* its cap; *12*, the intermediate, and *13* the final, overflow valve; *14* and *15*, the overflow valve stem and lever, respectively; *S*, the steam connection; *W*, the water connection; and *N*, the overflow.

The sectional view here presented has been taken in two vertical planes, so as to show the arrangements of the various tubes, and the overflow centerpiece, with its levers, valves, etc.

The intermediate overflow valve *12* provides the steam and water from the lifter with a free escape to the atmosphere, enabling a vacuum to be formed and the water raised. The final overflow valve permits water to escape from the discharge chamber until the jet is formed and sufficient steam is being used to force the water into the boiler.

42. Method of Working.—To start the injector, pull back lever *H* until the resistance of the steam valve *5* is felt; this allows steam that has come in through holes *a*, *a* of the steam valve to pass by auxiliary valve *6* and flow around to the lifting jet *1*, as shown by arrows *x*. The regulating valve being now opened slightly by means of wheel *G*, allows steam to flow through *1* into the lifting combining tube *2*, and lift the water through pipe *W*. The water passes through tube *2* into chamber *A*, as shown by the arrows *y*, past intermediate overflow *12* and out the final overflow. When the water shows at overflow, steadily pull back lever *H* as far as it will go. The steam then coming through valve *5* and tube *3* carries the water through the forcing combining tube *4*, *4* and through check-valve *10* into the boiler, as shown by the arrows.

The lever *H* must not be pushed in at all with a view to regulating the feed, but must be pulled clear out. The feed is regulated by the wheel *G*; to increase the amount of water raised to the injector, turn this wheel to the left; to decrease it, turn the wheel to the right.

To use as a heater, close the overflow by lifting the side links *B* from the pins, and pulling the links back. This will close the overflow valve *13*, and so prevent any overflow taking place out of the nozzle *N*. Then admit steam to the injector by pulling lever *H* back slightly.

HANCOCK INSPIRATOR

43. Description.—An **inspirator,** or double-tube injector, consists of two parts. The first part, called the *lifter*, raises the water and delivers it to the second part under a head or pressure. The second part, the *forcer*,

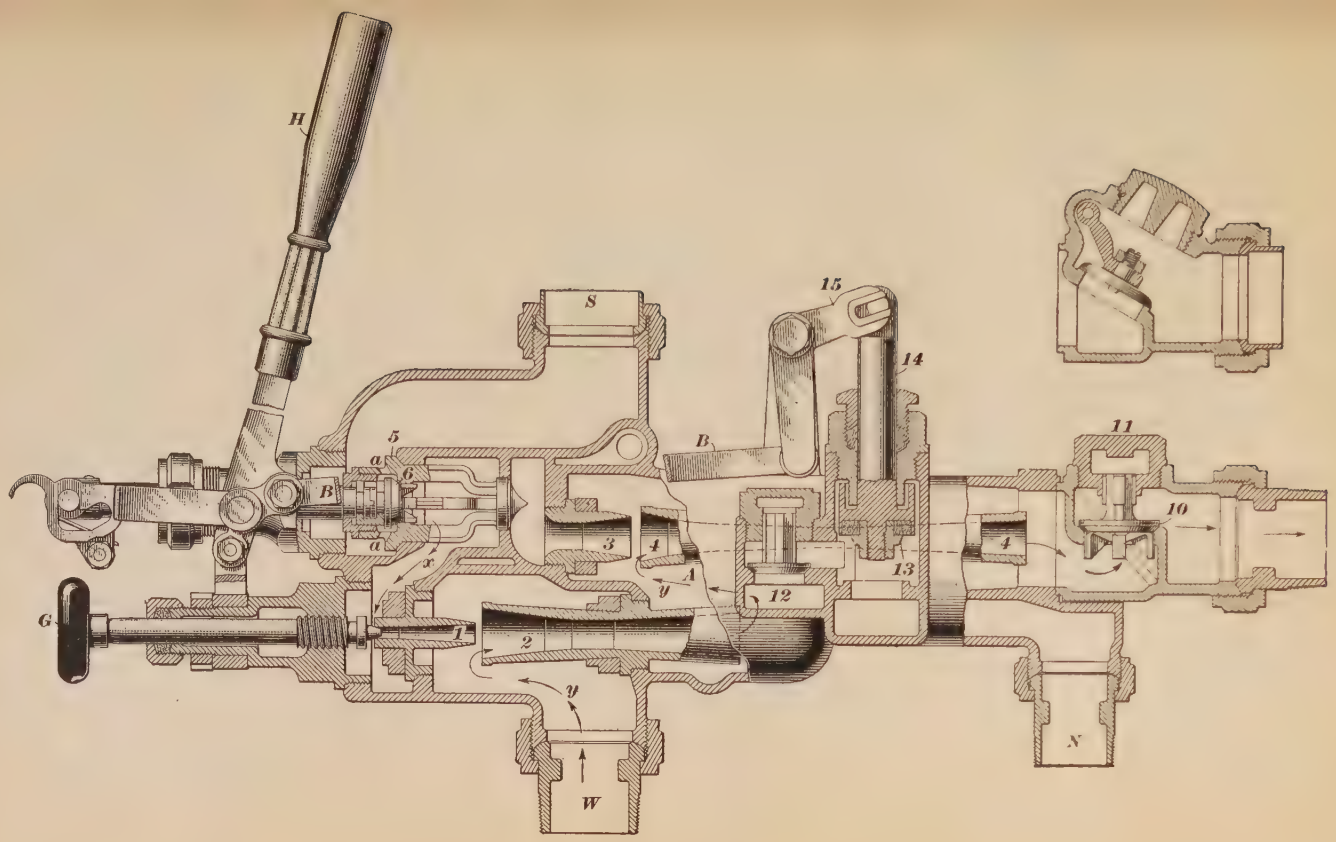

FIG. 18

takes the water from the first part and forces it into the boiler. Double-tube injectors have this advantage over single-tube injectors: they are more nearly self-regulating, since a rise in boiler pressure increases the flow of steam through the lifter and forcer in the same proportion.

In Fig. 19 is shown a sectional view of the latest form of **Hancock inspirator.** *1* is the lifter nozzle, and *2* the lifter tube; *3* is the forcer nozzle, and *4* the forcer tube; *5* is the lifter steam valve; *6*, the main steam valve, consisting of parts *a* and *b*; *7*, the intermediate overflow valve; *8*, the overflow valve; *10*, the check-valve; and *14*, the regulating valve. The inspirator should be so placed that the overflow nozzle *N* will be above the level of the water in the tank.

44. Method of Working.—To start the inspirator, draw the lever *H* back slightly until the resistance of the main steam valve is felt. When water is lifted, pull the lever steadily back to the stop. The inspirator will then be in full operation. When the pin *p* in the wheel of the regulating valve *14* is at the top, the inspirator will deliver its maximum quantity of water. To reduce the feed, turn the regulating wheel to the right. This valve takes the place of the water valve in the supply pipe, and by means of it the rate of delivering water may be regulated from the maximum to the minimum amount without touching the lever *H*. When the lever is slightly drawn back to raise the water, the lifter steam valve *5* is drawn from its seat on steam valve *6*; steam then flows from the boiler through pipe *S*, past valve *5*, through valve *6*, as shown by the arrows, and thence through the lifter steam nozzle *1*. The steam then passes through tube *2*, overflow valves *7* and *8*, and out of the nozzle *N*, creating a vacuum in *W* and raising the water, which at first flows out of the overflow nozzle also. The lever *H* is then pulled back to its full extent, which opens the main valve *6* wide at both *a* and *b*, while at the same time it closes the overflow valve *8* (see Figs. 19 and 20), and causes the water in chamber *h* to be put under pressure by the lifting apparatus. Steam then flows past valve *6* at *a* and *b* into

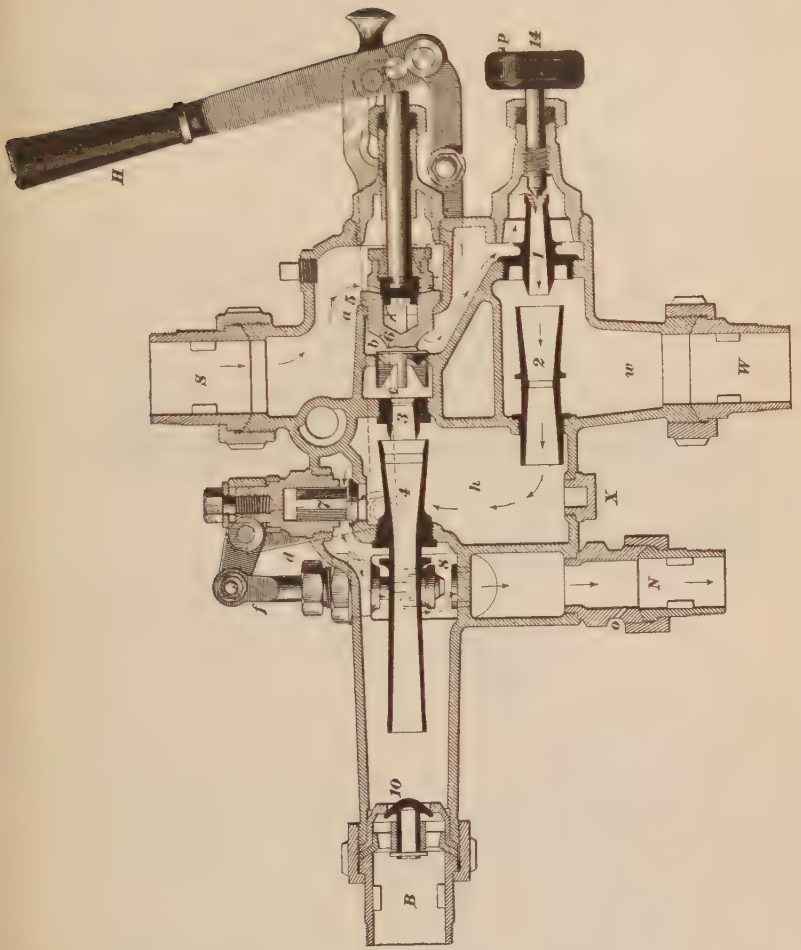

FIG. 19

chamber *c*, and through forcer steam nozzle *3* and combining tube *4*, where the steam is condensed by the water, which it heats, and to which it imparts sufficient velocity to force open the boiler check *10*. Intermediate valve *7* closes, preventing water getting back into chamber *h*. Fig. 20 shows how the lever *H* is connected to the overflow valve *8* by connecting-rod *e*, bell-crank lever *d*, and valve stem *f*. When the lever is pushed forwards to close the steam valve *6*

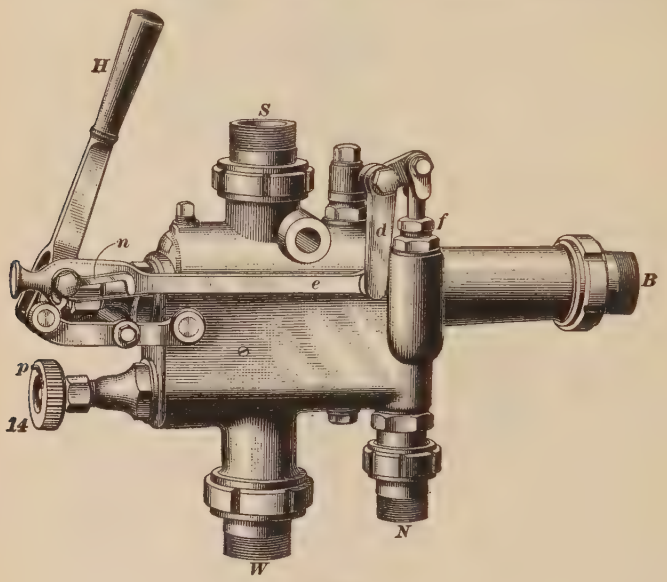

FIG. 20

it operates the bell-crank lever and opens the overflow; when it is pulled back to open the steam valve, it closes the overflow. In order to prevent siphoning water through the overflow pipe when the injector is shut off, a small air hole *o* is drilled in it.

To use as a heater, throw back the cam *n*, so as to disengage the connecting-rod from the lever, and then pull back the connecting-rod by hand to close the overflow; open the regulating valve *14*, and by means of the lever *H* regulate the quantity of steam to be used.

INJECTOR TROUBLES

45. Conditions Assumed.—In discussing the difficulties that are experienced in the working of injectors, it will be assumed at the outset that the injector itself is not unduly worn, but is in fairly good condition, and that the troubles are brought about by other causes. Also, for present purposes, the suction pipe, hose, strainer, and boiler delivery pipe and check-valve will be regarded as parts of the injector, since a disorder in any of these affects the working of the injector itself. In searching for the cause of a trouble, therefore, the suction and delivery pipes should be as carefully inspected as the injector.

46. Failure to Raise Water.—The causes that prevent an injector from raising water are:

1. *Suction Pipe Stopped Up.*—This may be due to a clogged strainer, collapsed hose lining, or to the pipe being stopped at some point. This prevents water from coming through, and is the most frequent cause of an injector not priming. In case the suction pipe is clogged, close the overflow valve and open the steam valve just sufficient to blow steam back through the pipe and force out the obstruction.

2. *Leaks in Suction Pipe.*—This allows air to enter and prevent the injector forming the required vacuum.

On some types of engines siphon pipes are used instead of tank valves. These are practically an extension of the supply pipes, and any leaks in the siphon above the level of the water in the tank will affect the priming of the injector. Where bad water is used, the siphon pipes pit in a few months, so that the injectors will not prime if the level of the water in the tank is below the holes in the pipes. The siphon pipes should be tested by stopping the lower end of the pipes and putting steam or air pressure in the pipes. Another method is to lift the siphon pipes out of the tank and test under pressure; also, if pitted, the siphons should be hammered so as to find out whether or not the pits extend through the pipe.

3. *Water in the Supply Pipe Too Hot.*—This may be due to a leaky steam valve in the injector, or to leaks in the boiler check and line check. The purpose of the line check-valve is to prevent the steam and hot water from flowing back into the injector, should the boiler check-valve leak. Also, it prevents the pressure in the delivery pipe from dropping rapidly when the injector is shut off, thus allowing the boiler check to slam on its seat and injure both the valve and its seat.

The reason why hot water in the suction pipe affects the operation of the injector is as follows: Experiment has shown that water will boil at about 380° F., under a gauge pressure of 180 pounds; at 212° F., at an atmospheric pressure of about 14.7 pounds; and at about 160° F., in 10 inches of vacuum. Now, when the lifting jet of an injector is turned on, a vacuum is formed in the suction pipe; and, if the water there is at a temperature of 160° to 175° F., it gives off steam vapor, which destroys the vacuum.

To start the injector under these conditions, turn on the priming jet, close the overflow valve just long enough for steam to blow back into the suction pipe and force the hot water into the tank, then quickly open the overflow valve; the cool water entering the suction pipe will then rise and pass out of the overflow.

4. *Hot Water in Tank.*—In case the water in the tank has been heated to such a temperature that the injector will not handle it, open the manhole cover on the tank and, if possible, cool it off by the addition of cold water.

As was shown in Art. **20**, low-pressure steam will handle hotter feedwater than high-pressure steam; consequently, if the steam is throttled down at the boiler steam valve until the injector will just barely pick up the water at the overflow, it may be possible to cause the injector to work at a minimum capacity and thus supply some water to the boiler. Often, disconnecting the overflow pipe will give a freer opening for the overflow to the atmosphere, and the injector will prime when otherwise it will not. In the case of a Hancock inspirator, removing the plug X until the inspirator primes will often prove successful.

When steam is turned back into the tank to prevent the pops blowing, or to heat the water when standing still, use only one injector, as this will heat the water in one leg of the tank only.

5. *Obstruction in Tubes.* There may be an obstruction in the lifting or combining tubes, or the spills may be clogged up. This interferes with the free passage of the steam to the overflow and a steam pressure instead of a vacuum will be formed in the suction pipe.

Frequently, with the Hancock inspirator, the space back of the lifter steam valve *5* and the main steam valve *6* becomes blocked with mud and lime, so that when an attempt is made to open the lifter valve *5* for the purpose of priming, the main steam valve *6* opens instead. This admits too much steam to the lifter nozzle and lifting tube, and creates too much pressure at this point, causing the steam to blow back into the feedpipe instead of lifting the water.

With the Simplex injector, a leaky by-pass check-valve *19*, Fig. 16, will allow steam to blow directly into the suction pipe in priming the injector if the plug valve *35* is open. Closing the plug valve will stop this flow of steam and enable the injector to prime.

6. *Intermediate Overflow Valve Stuck.*—With a double-tube injector, the intermediate overflow valve may stick shut, so that all steam and water must pass through tube *4*, which is too small to allow the injector to prime.

7. *Screw Monitor Troubles.*—When trouble is experienced with the screw monitor injector not priming properly, it may be due: to a leaky steam valve *5* or a cut or worn overflow nozzle *N* preventing sufficient vacuum being formed; to the overflow pipe being partly filled up with scale or mud, frozen shut, or filled up with some other solid matter that prevents a free outflow of water; or to the lifting nozzle *4* being worn out of round or otherwise defective. Also, the injector will not prime if the thread on the stem is stripped so that the valve cannot be unseated; if the primer valve *3* is loose or broken from the stem; if the priming tube *T* or nozzle *4* is

stopped up; or if the primer handle *j* is loose so that the valve cannot be unseated.

47. Injector Primes, But Will Not Force.—In some cases an injector will lift water but will not force it into the boiler when the forcing steam valve is opened; or, it may force part into the boiler and the rest out of the overflow. When it fails to force, the trouble may be due to one of the following causes:

1. *Choked Suction Pipe or Strainer; Partly Closed Tank Valve; Collapsed Hose Lining; a Kink in the Hose; or an Obstruction in the Overflow Passage.*—If the suction pipe or the strainer is partly choked; or the tank valve is partly closed, or the hose lining collapsed, the injector will be prevented from lifting sufficient water to condense all the steam issuing from the forcer steam nozzle. The uncondensed steam, therefore, will gradually decrease the vacuum in the combining tube until it is reduced to about 7 or 8 inches, when the injector will break. (It is to be remembered that, when the injector is operating, it is the vacuum in the combining tube that causes the water to be raised.)

The remedy in case the tank valve is partly closed is, of course, to open it. In case of a choked suction pipe or a collapsed hose lining, convert the injector into a heater, and blow out the obstruction, as already explained. If the trouble is due to a collapsed hose lining and cannot be remedied by blowing steam through it, it may be overcome by turning the hose end for end. The hose should have an easy curve from the tender connection to the suction pipe; if the hose kinks, it will choke the supply of water.

2. *Wasting at Overflow.*—This, in single-tube injectors, may be caused by either too great or too small a supply of water for the pressure of the steam. In the case of too much water, the water will come out through the overflow only slightly warm; the remedy is to reduce the supply of water passing into the injector until the jet is formed. In the case of too little water, the water will come from the overflow at a high temperature and mixed with steam; the remedy

is to increase the supply of water or reduce the supply of steam until the jet forms. If an air-tight joint is made at the injector overflow by the overflow pipe, the water will, when once started priming, continue to flow out of the pipe while the injector is not forcing, as it will make a siphon. To prevent this, a small air hole is made in the overflow *N* to admit air at this point and prevent siphoning. This opening also acts as a telltale to show when the jet breaks.

An obstruction in the delivery tube, the tube cut or worn, the line check broken, or the boiler check stuck shut or not open fully will cause the injector to waste at the overflow also. In case the frost cock in the delivery pipe is open, it may waste enough water to reduce the pressure in the delivery pipe so that the boiler check will not be opened, in which case the injector will waste at the overflow.

3. *Supply Pipe Leaking.*—The leak may not be sufficient to entirely prevent the injector from lifting water, but the quantity lifted may be insufficient to condense all the steam, which therefore destroys the vacuum in the combining tube. Or, the water in the combining tube, not being a solid stream, will not be acted on by the steam properly and the jet will break. With a restarting injector, the jet will be formed again as soon as the stream of water becomes solid again; with other types of injectors steam must be shut off and the injector restarted. A slight leak may exist that will simply cut down the capacity of the injector. In such a case, the injector will work noisily, on account of the overflow valve seating and unseating itself as the pressure in the combining tube varies, due to the leak.

To test for leaks in suction pipe, close the overflow valve, partly open the steam valve, and then close the tank valve sufficiently to produce a slight pressure in the suction pipe and hose. Any leaks will then allow steam to escape, and they can be located by a close inspection of the pipes and joints.

4. *Boiler Check-Valve Stuck.*—If completely closed, an automatic injector will raise water but will not force it.

If partly open, the injector will force some water into the boiler and the remainder out of the overflow. A positive or

closed overflow injector will break and steam will blow back into the tank. In case the check-valve cannot be opened wide, water may be saved by throttling both steam and water until the overflow diminishes, or, if possible, ceases. The steam should be throttled at the valve in the boiler steam connection, however, and not at the steam valve of the injector, as throttling tends to superheat the steam, and an injector will not work as satisfactorily with superheated steam as without. By throttling the steam at the boiler, the excess of heat due to this throttling will be lost before the steam reaches the injector. Saturated steam contains just sufficient heat to maintain it in the state of steam and any loss of heat causes some of it to condense. Superheated steam has a temperature higher than that of water from which it would be formed at any pressure.

If the check-valve is stuck shut, it can sometimes be made to work again by tapping lightly on the cap, the bottom of the valve case, or the delivery pipe. Sometimes a boiler check can be opened by starting the injector and gradually closing the water valve so as to decrease the supply and increase the pressure that the water exerts against the check.

If the boiler check sticks open and the line check in the injector does not prevent the water from coming from the boiler when the injector is shut off, it can usually be reseated by opening the frost cock in the delivery pipe or slacking away on the union and tapping lightly on the cap, the bottom of the valve case, or the delivery pipe. This method can be aided by pouring cold water over the check-case. This contracts the case; when it expands the valve will loosen. If the check cannot be closed, close the overflow valve and water-regulating valve, when there is one, which will prevent the water from the boiler passing back through the injector. If the injector is not provided with a water-regulating valve, or if it is not water-tight, reduce the pressure of steam in the boiler, disconnect the hose from the feed-pipe, drive a wooden plug into the end of the feedpipe, connect up the hose to the feedpipe to hold in the plug, and supply the boiler with the other injector.

When a check has been giving trouble by sticking, it is advisable to stop the injector by closing the water valve and then the steam valve. The steam then condenses quickly and allows practically full boiler pressure to be exerted suddenly to close the valve. This will usually force the valve to its seat. If the valve cannot be seated, close the water valve and the overflow valve. This will retain the hot water from the boiler, so that the water in the tank will not be overheated, and there will be no waste at the overflow.

To locate the difference between a leaky steam valve and a leaky boiler check, shut off the injector steam supply at the boiler; if it is the steam valve in the injector that is leaking, this will stop the flow of steam at the overflow; but if a leaky boiler check is giving the trouble, the steam and hot water will continue to pass out of the overflow.

5. *Combined Boiler Check and Stop-Valve Stuck.*—The combined boiler check and stop-valve is so constructed that communication between the boiler and boiler check may be closed by closing the stop-valve; this permits the removal of the boiler check without blowing the steam off the boiler. In case the boiler check sticks open, or is held from its seat by scale or dirt, the trouble may usually be overcome in the following manner: First close the stop-valve to prevent the escape of water from the boiler back through the delivery pipe; then prime the injector and open the stop-valve, when the injector may be put to work. Should this method fail to remove the cause of trouble, again close the stop-valve, take out the check-valve, and remove the obstruction by hand.

Should the boiler check become stuck or closed, first close the stop-valve and then open the check-case vent (if there is one), to drain the pressure from the cavity between the stop-valve and the boiler check; after this the boiler check may be removed and cleaned.

6. *Obstruction in Delivery Tube.*—Any obstruction in the delivery tube, such as cotton waste, scale, or coal, will cause a heavy waste of water from the overflow. To remedy this, the tube will probably have to be removed and cleaned. In

many types of injectors, it is often possible to remove the steam valve and remove or break up the obstruction by means of a piece of stiff wire or some other long, slender instrument.

7. *Leaky Overflow Valve.*—With an automatic overflow injector, this allows the air to be drawn into the injector, and, if the leak is sufficiently great, it diminishes the capacity. A leaky overflow valve with a single-tube automatic injector is indicated by the boiler check chattering on its seat.

A leaky final overflow valve in a double-tube injector will cause a waste of water at the overflow. This may be due to any of the following causes: Cut or worn valve face or seat; cinder or scales lodging under the valve, not allowing it to seat properly; or with the Hancock inspirator or Metropolitan injector, too much packing in the stuffingbox around the overflow-valve stem, which allows the packing nut to stick up so high that the clevis of the stem strikes it and does not allow the valve to move down to its seat.

8. *Leaky Steam Valve.*—A leak at the steam valve causes a constant blow of steam at the overflow when the injector is shut off. In the Hancock inspirator, if the connecting-rod *e* is too long, the bell-crank *d* will strike the casing of the final overflow valve and prevent the valve from closing, thus causing a leak of steam from the overflow.

9. *Tank Air-Tight.*—If the tank becomes air-tight, by freezing or otherwise, so that air cannot enter as fast as the water is withdrawn by the injector, the air entrapped in the tank will expand as the water is withdrawn, and the pressure exerted by it will therefore be lessened. After a time, the pressure of air in the tank will not be sufficient to force water into the injector, and the latter will break and refuse to lift again. The remedy is to keep open communication between tank and atmosphere.

10. *Injector Choked With Lime.*—It is essential to the proper working of an injector that the interior of the tubes should be perfectly smooth and of the proper bore. As, in course of time, they "lime up," the capacity of the injector decreases until finally it refuses to work at all. If the water

used is very bad, it becomes necessary to frequently cleanse the tubes of the accumulated scale. This may be accomplished by putting the parts in an acid bath, allowing the acid to remove the scale. The bath should consist of 1 part of muriatic acid to 10 parts of water; the tubes should be removed from it as soon as the gas bubbles cease to be given off. The acid combines with the lime and forms a gas, and as long as there is lime to combine with, it will not attack the metal of the tubes. After the lime has all combined, however, the acid will attack the tubes, with the result that the inner surface will become pitted and rough, which will affect the working of the injector.

Should a tube become loose in an injector, it will seriously interfere with its operation, and in most cases will entirely prevent its working; therefore, where tubes are replaced, care should be take to screw them firmly to their proper position.

If the tubes of an injector are badly cut or worn out of shape, it will prevent the injector from working properly.

11. *Tubes of Improper Shape.*—The tubes of an injector using a moderate pressure of steam—140 pounds or less—are of a different shape from the tubes of an injector built to work at pressures of 140 pounds to 200. For that reason an injector that has given satisfaction on a boiler carrying a moderate pressure may refuse to work at the higher pressures.

It will work all right in the roundhouse with less than the working pressure, say 140 pounds, but when on the road with a full pressure it begins to waste water and steam at the overflow and finally breaks. The remedy for this trouble is to take out the low-pressure tubes and replace them with high-pressure tubes. As this cannot be done on the road, use a reduced steam pressure at which the injector will operate until such time as the tubes can be changed.

BOILER ATTACHMENTS
(PART 2)

LOCOMOTIVE LUBRICATORS

SIGHT-FEED LUBRICATORS

GENERAL REMARKS

1. The first *up-drop* lubricator was introduced in 1885, and the first double *sight-feed* lubricator in 1886, while the triple sight-feed lubricator made its appearance in 1888. Up-drop lubricators are so named from the fact that the oil on its way to the oil pipes flows upwards, drop by drop, through the water in the feed-tubes. A **sight-feed lubricator** is one in which the feed-tubes, or chambers, through which the drops of oil pass upwards are of glass; this permits the operator to see how the oil is feeding, and he can count the drops and adjust the feed until the lubricator delivers the proper number of drops per minute. A **double** sight-feed lubricator consists really of two single sight-feed lubricators combined in one, as a matter of convenience, while a **triple** sight-feed lubricator consists of a combination of three single lubricators. A double sight-feed lubricator furnishes and regulates the supply of oil to the two cylinders of the engine. A triple sight-feed lubricator furnishes and controls the lubrication for both cylinders of the engine and for the steam cylinder of the air pump. Sight-feed lubricators having seven or more feeds are also manufactured. Since the double and triple lubricators consist, respectively, of two and of three separate ones combined, or, in other

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words, since each feed is connected with its separate oiler, it follows that the feeds many be worked singly, two at a time, or all together, without affecting the operation of any one feed.

PRINCIPLE OF OPERATION

2. The principle on which the sight-feed lubricator operates can best be explained by reference to Fig. 1, which represents a conventional form of lubricator. *R* is an oil reservoir, and *A* a chamber above it, communicating with

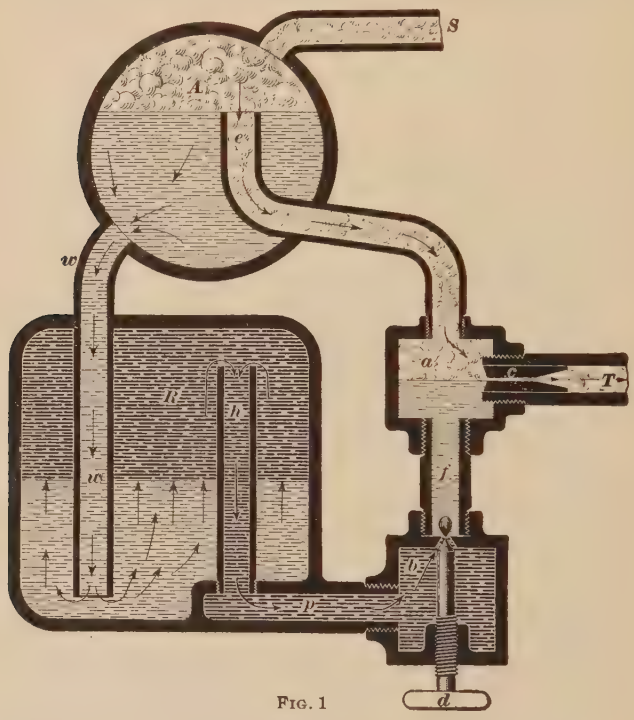


FIG. 1

the boiler through the steam connection *S*. Into this chamber, called a **condenser,** steam enters, and part of it is condensed, maintaining the chamber filled with water up to a certain level, as shown. A tube *w* connects the condenser

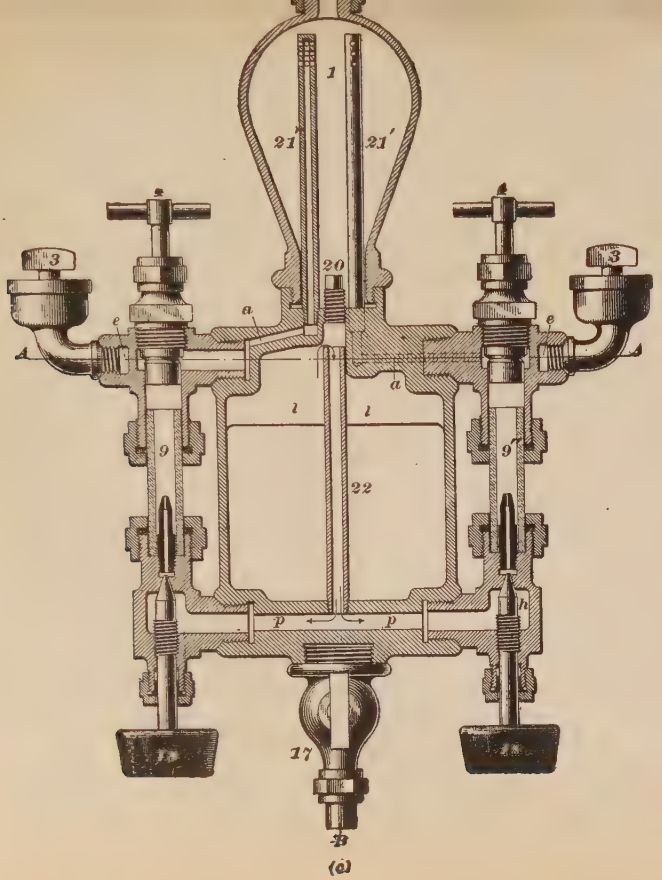
with the bottom part of reservoir *R*. The feed-glass *f* is in communication with the oil reservoir through chamber *b* and passages *p* and *h*.

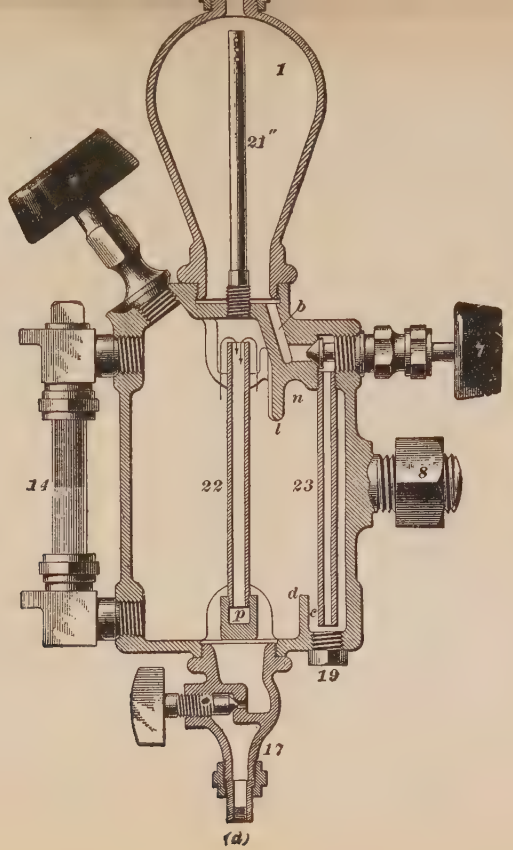
The chamber *a*, situated above the glass *f*, communicates with the steam space *A* through a tube *e*, called an **equalizing tube.** The pipe *T* leads to the steam chest of the engine. The water in *A* flows into the reservoir *R* through the pipe *w*; and as the oil in chamber *R* is the lighter of the two, it floats on the water. Boiler pressure is exerted on the water in *A*, and is transmitted through the water in tube *w* to the water in *R*, and so to the oil, as shown by the arrows. The total pressure acting upwards on the oil is therefore equal to the pressure of the steam plus the pressure due to the head of water in the condenser. These two pressures are acting to force the oil through passages *h* and *p* into *b*, as shown by the arrows. Steam pressure is also exerted on the water in chamber *a*, where it acts downwards and resists the lifting effect of the steam (already mentioned) on the body of water in *a*. It will be seen that while steam in *A* is tending to force water down the tube *w* and so raise its level in *R* and transmit its pressure through *R*, *h*, *p*, *b*, and *f*, to that in *a*, steam of the same pressure in *e* is acting to keep the water in *a* down. So that as far as the steam pressures are concerned, the whole body of liquid (water and oil) tends to remain motionless.

It is not the pressure of the steam that forces the oil through the passages *h* and *p* into chamber *b*, but the pressure due to the head of water in the condenser, and this head is made such as will give the best results. When once the oil enters *b*, a drop floats upwards through the water, regardless of the pressure in *f*. The statement is frequently made that the successful working of the lubricator depends on the equalizing feature. This simply means that the pressure of the steam in chamber *a* must be maintained equal to the pressure, due to the steam, in chamber *b*; for, if they are not equal, the action of the lubricator will be irregular. The choke plug *c* restricts the flow of steam out of the lubricator, and thus maintains a steady pressure in the chamber *a*. If

4. Four sectional views of this lubricator are given in Fig. 3. View (*b*) shows the lubricator partly in elevation and partly in section, the section being taken on the line *C C* of view (*a*); view (*c*) is a section on line *A A* of views (*a*) and (*b*); view (*a*) is a section on line *A A* of view (*c*); and view (*d*) is a section on the line *B B* of views (*a*) and (*c*). Inside the condenser are three equalizing tubes *21*, *21′*, and *21″*, one for each feed-glass. In view (*a*), the holes corresponding to *21* and *21′* are seen but not that of *21″*. In view (*c*), *21″* is seen in section and *21′* in elevation. In view (*d*), *21″* is seen in elevation; *21* and *21′* are not seen in this view. Small holes are drilled in the top of each tube, and the lower end of each is connected to its feed-glass by a small passage *a*, views (*a*) and (*c*). It is the water of condensation that passes through these tubes that keeps the feed-glasses full. (In some later types of the Nathan lubricator the equalizing tubes are placed outside the condenser).

The condenser *1*, view (*d*), is connected with the oil reservoir through the passage *b*, water valve *7*, and water tube *23*, the lower end of this tube opening into the pocket *c*, views (*d*) and (*a*), this pocket being formed by the partition *d*. When, before refilling the oil reservoir, the water is drawn off through waste cock *17*, pocket *c* remains full of water; and, as the lower end of the tube *23* is below the surface of this water, oil cannot "back up" into the tube when the reservoir is filled, since it floats on the water in the pocket. Another pocket *n*, situated directly above pocket *c*, is formed by the partition *l*; see views (*c*) and (*d*). When the lubricator is being filled, the oil rises until it reaches the bottom of the partition *l*, when the air that is trapped in the pocket *n* prevents the oil from entering, even though the reservoir is filled completely. The pocket *n* is provided to allow for the expansion of the oil when heated, should the reservoir be completely filled. The tendency of the oil to expand compresses the air in the pocket, and thus more space is provided, into which the oil expands. If this space were not provided and the water valves and regulating valves were closed, the force exerted by the oil in trying to expand would bulge or burst the reservoir.





59B—I L T 68C—266 § 12

Fig. 8

58905

(a)

The oil tube 22 is open at the top and is in direct communication with the reservoir *12*; its lower end communicates with the oil chamber *p*, which leads to the under side of each of the regulating valves *18*. The oil tube and chamber *p* are full of oil as long as there is any in the reservoir.

The condenser *1* always stands about four-fifths full of water that is condensed from the steam. When the water valve *7* is opened, the water can pass through passage *b*, valve *7*, and tube *23*, to the bottom of the oil reservoir. The oil floats on the water, and is thus forced upwards by the head of water, and then down the oil tube *22* and into chamber *p* by the head of water in the condenser. The steam pressures at the top and bottom of the feed-glasses neutralize each other. As the oil passes through the regulating valve, it forms a drop and floats upwards, and is carried into the oil pipe by the current of steam that is flowing through the equalizing tubes, hence out through the choke plugs *5* to the steam chest. As fast as the oil is used from the reservoir, its place is filled with water that flows from the condenser.

5. Refilling and Operating.—To refill the reservoir, close all the valves *18*, the steam valve *17*, and the water-valve *7*; draw off the water from the reservoir through the cock *17*; then remove the filling plug *2* and fill the reservoir with clean strained oil. Replace the filling plug, and open the water valve *7* and steam valve *17* immediately, whether the feeds are to be started or not. This is a precaution against the expansion of the oil bulging the reservoir, since, if the water valve is open, the oil will simply back up into the water tube *23* and condenser *1*, as the pressure increases in case the oil reservoir has been filled too full.

The safety valves *4* are to be used only in case a feed-glass breaks; in that event, close the safety valve *4*, and regulating valve *18* of the broken glass, and use the auxiliary hand oiler *3* until the glass can be replaced. The breaking of any one glass will not interfere in the least with the operation of the other feeds.

The steam valve *V* must always be opened before the engine leaves the roundhouse, and must be kept open as long as the engine is moving, regardless of whether the feeds are operating or not. It should be the first valve opened before leaving the roundhouse and the last valve closed on returning to it.

The water valve 7 should always be open except when the oil reservoir is being filled.

To start the feeds, open the regulating valves *18* and regulate until the desired number of drops per minute are being delivered. To stop the feeds, close the regulating valves. If the water valve 7 can be closed tightly it will stop the flow of water into the oil reservoir, and no oil will pass out through the regulating valves.

IMPROVED NATHAN LUBRICATOR

6. Description.—An improved form of Nathan triple sight-feed lubricator is illustrated in Fig. 4, in which view (*a*) is a section through the lubricator on the lines *B O C*, view (*b*); view (*b*) is a plan view; and view (*c*) is a section on the lines *A B*, view (*b*). The construction of the lubricator is very similar to that of the old lubricator, except that the equalizing tubes *21* and the passages in the body of this lubricator are made larger. Also, the air-pump sight feed *9'* is on the front of the cup, whereas the oil-pipe connection is at the back, the two being connected by a passage in the cup. The parts in these illustrations are numbered the same as in the illustrations of the old lubricator.

A steam-chest oil plug, view (*d*), is used with this lubricator, the bore of which must not be less than $\frac{3}{32}$ inch nor more than $\frac{1}{8}$ inch to give proper results. The object of this plug is to prevent oil being held up in the oil pipes, and its bore bears a certain relative proportion to the bore of the choke plugs *5* in the cylinder oil outlets.

7. Operation.—The directions for operating this lubricator are substantially the same as for the old one. To use hand oiler *3*, first close the outlet valve *Y*, then fill the hand

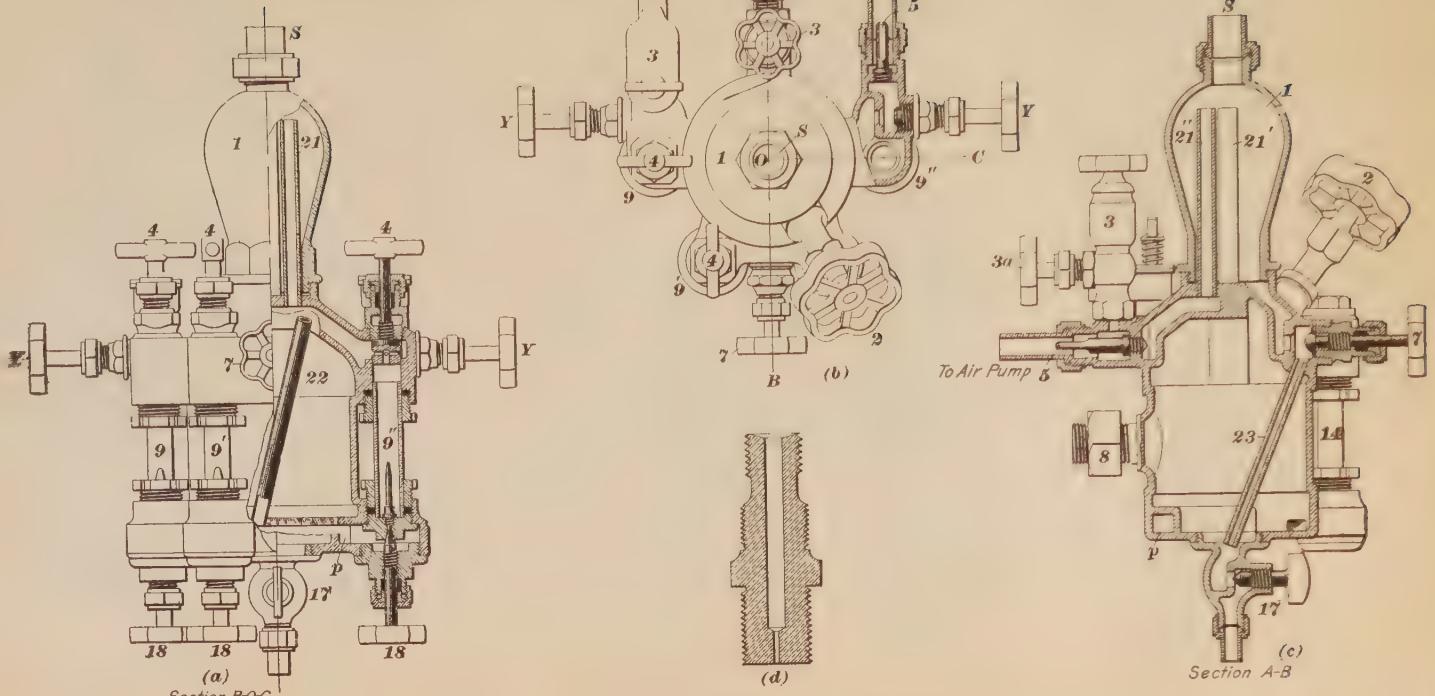

S
1
21
4
4
4
X
Y
7
22
9
9'
9"
p
17
18
18
18
(a)
Section B-O-C
A
To Cylinder
To Air Pump
To Cylinder
5
3
3
Y
Y
4
1
6
S
9
9"
C
4
9'
2
7
B
(b)
(d)
S
1
21"
21'
2
3
3a
To Air Pump 5
7
23
14
8
p
17
(c)
Section A-B

FIG. 4

oiler, open the oiler valve and, when the oil has passed into the oil pipe, close the hand-oiler valve and open the outlet valve *Y* wide.

The outlet valve *Y* must be kept wide open at all times, except when using the hand oiler, as directed above.

THE NATHAN BULL'S-EYE LUBRICATOR

8. The **Nathan bull's-eye lubricator** is illustrated in Figs. 5 and 6, in which Fig. 5 (*a*), (*b*), and (*c*) are three views of the complete cup, and Fig. 6 (*a*) a front sectional view, and (*b*) a side sectional view, showing its internal construction. *11* is the body or oil reservoir, which is of cast brass, with the sight-feed glasses *9*, oil passage *O*, and regulating valves *15* at the bottom. An oil pipe *18* extends from the oil passage *O* to the top of the reservoir and supplies oil to the regulating valves as long as there is any in the reservoir. A water pipe *19* extends from the water valve *7* to the bottom of the reservoir. When valve *7* is open, water from the condenser can pass freely into the bottom of the reservoir under the oil. Equalizing pipes *17* that are screwed into the top of the passages *p*, *p'*, and *p''*, and reach nearly to the top of the condenser, supply live steam to these passages, and keep the sight-feed chambers full of condensed water. The drain cock *14* can be attached to either side of the oil tank, as is most convenient. It is here shown in the right side with a plug *23* closing the left-hand opening. The water pipe *19* is passed through one of these openings and screwed into the water passage at the base of the valve *7*.

The observation, or sight, glasses, are shown in Fig. 6, view (*c*) being the glass, its washer, the packing ring, and the threaded follower, in the casing with all the parts in place ready to screw into the body of the cup. At *9* they are used to observe the rate of feed and at *13* to see when the supply of oil is nearly fed out. There is an extra casing and glass ready for use screwed into a pocket in front of the cup at *21*, shown in the side view (*b*), Fig. 6.

Drain valves *20* are connected to the sight-feed chambers; these valves can be opened to blow out dirty water or any

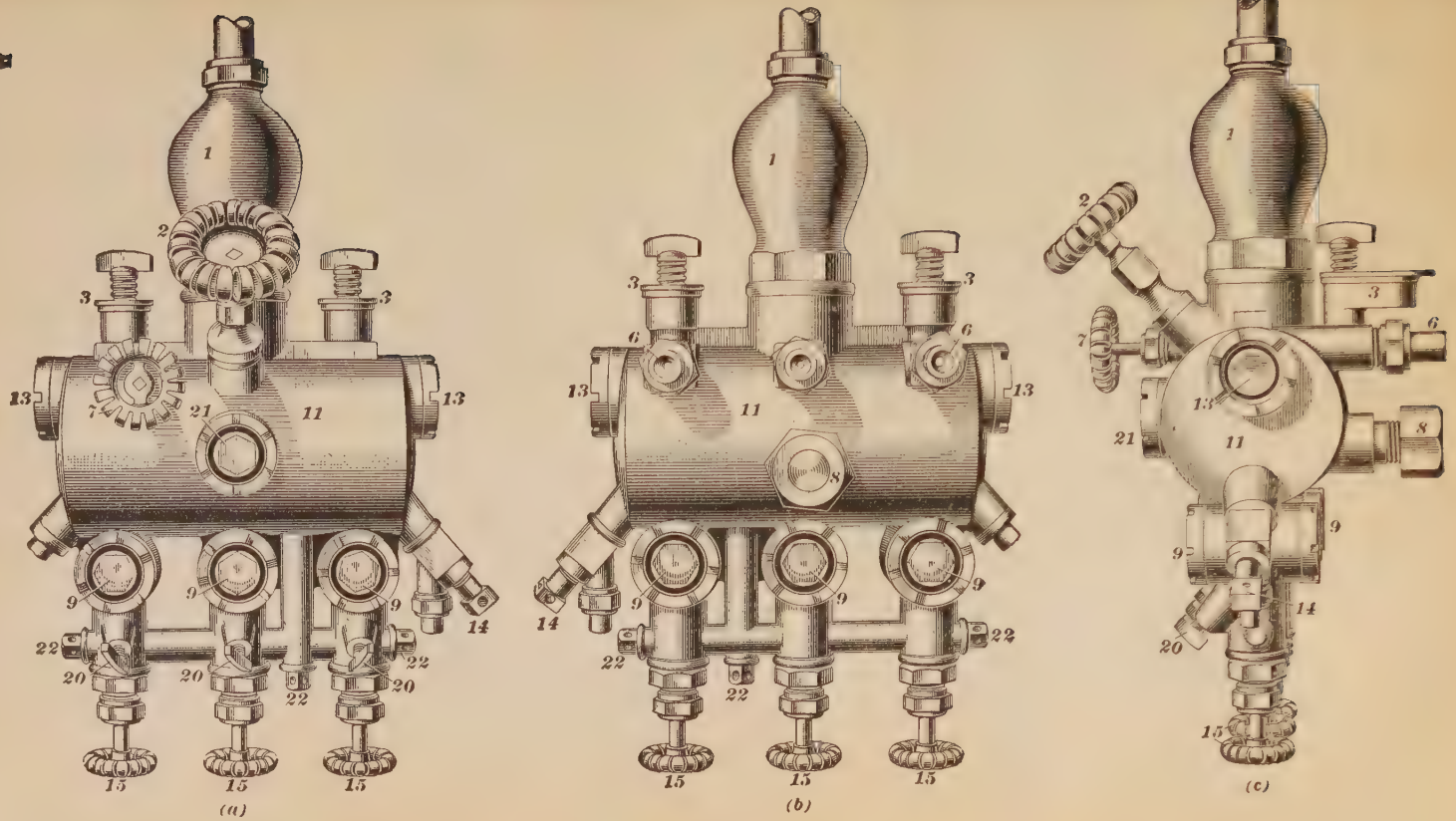

1
2
3
3
13
7
21
11
13
9
9
9
14
22
20
20
22
20
15
15
15
(a)
1
3
3
6
6
13
11
13
8
9
9
9
14
22
22
22
15
15
15
(b)
1
2
3
6
7
13
21
11
8
9
9
14
20
15
(c)

FIG. 5

obstructions in the chambers and clean out the sight-feed nipples *9a*. Choke plugs *5* are located in the passage where the oil leaves the lubricator and enters the oil pipes.

Auxiliary or hand oilers, one for each steam-chest oil pipe, are shown at *3*; they are similar to the oil cups used on the other patterns of Nathan lubricators.

A steam-chest oil plug is shown in Fig. 4 (*d*); it may be of any standard form but should be provided at the lower end with a drilled opening not less than $\frac{3}{32}$ inch nor more than $\frac{1}{8}$ inch in diameter, in the same manner as illustrated. This plug is absolutely necessary for the proper working of the lubricator; it is used in addition to the choke plug *5* in the cup.

DETROIT LUBRICATOR

9. Description.—Fig. 7 illustrates the **Detroit triple sight-feed lubricator** as used on locomotives, (*a*) being a front view and (*b*), a side view. *A* is the oil reservoir; *B*, *B*, the auxiliary oilers; *C*, the connection to the boiler; *D*, the water valve; *E*, *E*, the regulating valves for engine-cylinder feeds; *F*, the condenser; *G*, the drain cock; *H*, *H*, sight-feed glasses to engine-cylinder feeds; *I*, the regulating valve for the air-pump feed; *K*, the air-pump feed-glass; *M*, a steam valve in the boiler connection; *O*, the filling plug; *R*, the air-pump connection; *T*, *T*, water plugs; and *a*, *e*, equalizing tubes for the air-pump and engine-cylinder feeds, respectively. The equalizing tubes of this lubricator are placed outside the condenser, and connect with it above the steam connection *C*. The condenser therefore fills with water up to the level shown by the dotted lines; any surplus condensation will drain back into the boiler.

Fig. 8 (*a*) shows one of the sight-feed arms in section; part of the oil reservoir is represented as broken away, in order to show the oil pipe *37* leading to the feed-glass. There are two oil pipes *37* and one *38* in the reservoir, views (*c*) and (*d*), one for each feed-glass; pipe *38*, which connects with the air-pump feed, is a little shorter than either of the other two. The water tube, through which

To Boiler
16
17
1
3
p
p'
p''
11
13
9
9a
22
23
15
(a)
To Boiler
16
17
1
3
6
5
p'
19
C
9
9a
11
21
2
7
20
15
(b)
(c)

FIG. 6

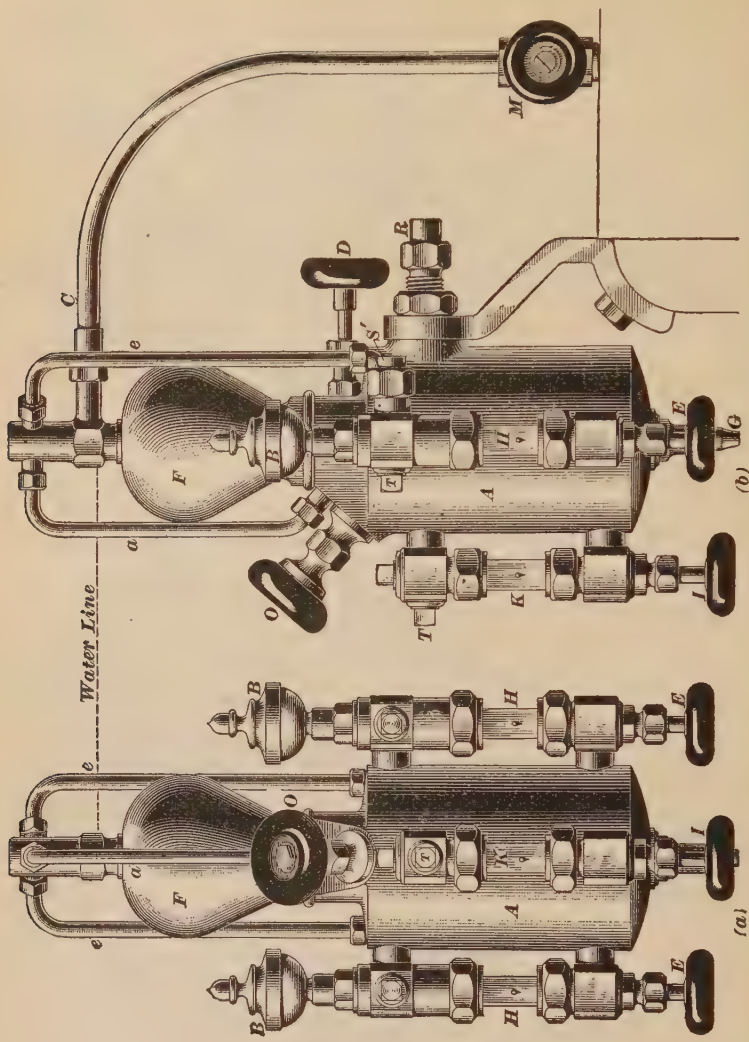


FIG. 7

the water passes from the condenser to the bottom of the oil reservoir, is not seen in the figure. View (*b*) is taken looking at (*a*) in the direction of the arrows; it shows another section of a feed-arm. The check-valve *s* is used as a safety device, closing automatically when the glass breaks, and thus preventing the escape of steam. The passage through which the oil flows from the hand oiler *B* to the oil pipe is indicated by small arrows.

View (*c*) is a section taken through the upper feed-arms; it shows the oil pipes *S*, *S'* that lead to the engine cylinders and the air-pump oil pipe *R*. The choke plug *c* for each oil pipe is also shown. The equalizing tubes *e* connect with the reservoir as shown, and communicate with the upper feed-arm and the choke plug by a passage *e'* in the casting, as shown by the arrows.

View (*d*) is a vertical section through the air-pump feed-glass *K* and the air-pump connection *R*; this view shows the oil passage *r* through the upper part of the reservoir body. The air-pump equalizing tube *a* connects with the passage *r* as shown. The steam passing through the equalizing tubes maintains a pressure on the water in the feeds equal to that in the condenser; and the pressure exerted by the head of water in the condenser forces the oil through the feed-valves. As fast as the oil is used from the oil reservoir, it is replaced by water from the condenser.

10. Refilling and Operating.—To refill the reservoir, close valves *D*, *E*, *M*, and *I*; draw off the water from the reservoir, and fill through the filling-plug opening *O* with clean strained oil; then reopen the valves *D* and *M* immediately. Regulate the feeds by means of the valves *E*, *I*. In the event that there is not enough oil to fill the lubricator, use warm water to make up the quantity.

To operate the lubricator, open valve *M*, Fig. 7 (*b*), and then valve *D*, and adjust the feeds by means of the regulating valves. If a glass breaks, the auxiliary oilers *B* are to be used in the same way as the old cab oilers, that is, by closing the throttle while feeding, the oil being then drawn down

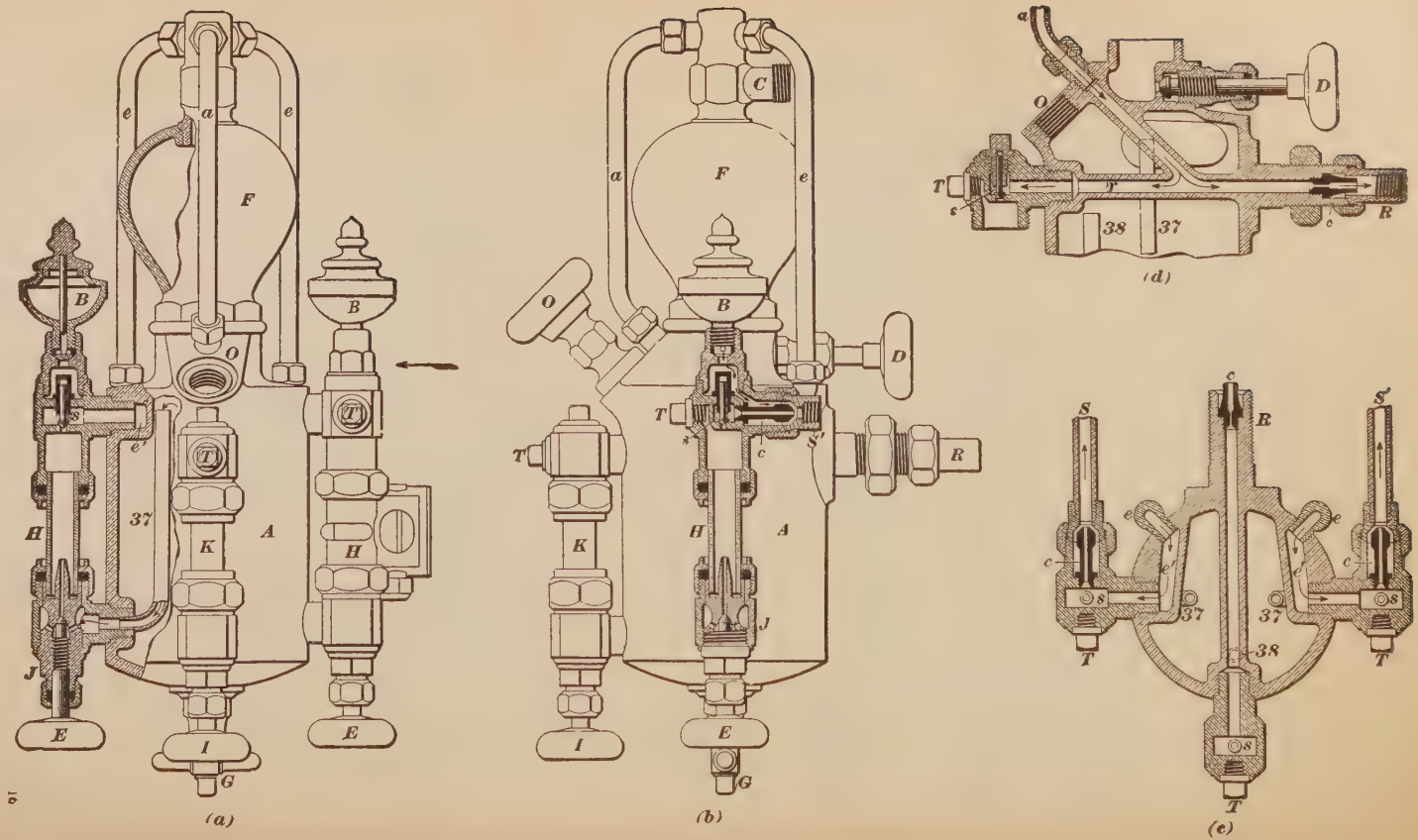

a
e
e
F
B
B
O
T
T
e'
S
H
37
K
A
H
J
E
E
I
G
(a)
C
a
F
e
O
B
D
T
T
s
c
S'
R
H
A
K
J
I
E
G
(b)
a
O
D
T
T
s
c
R
38
37
(d)
c
S
S'
R
e
e
c
c
e'
e'
s
s
37
37
38
T
T
T
(c)

FIG. 8

into the steam chest by suction—to express the action in popular terms.

The steam valve *M* must always be open when the engine is moving, and the valve *D* should only be closed when filling the oil reservoir.

IMPROVED DETROIT LUBRICATOR

11. Construction.—An improved form of the Detroit lubricator is illustrated in Fig. 9. View (*a*) is a front elevation with part of the oil reservoir and right sight feed broken away to show the construction of the regulating valves *E* and by-pass valves *j*. View (*b*) is a side elevation with the feed-arm broken away to show the passage leading from the feed-glass *H* through the safety valve *s* into the oil pipe to the cylinder. (*c*) is a cross-sectional view taken on the sectional line *A B*, view (*a*). It will be seen that while there are some slight changes, the general construction of this style of lubricator is, in many respects, very similar to the old one. The parts in these illustrations are numbered the same as in the illustrations of the old lubricator.

It will be noticed that this lubricator has but two outside equalizing tubes *e*, *e*, the one for the air-pump feed, marked *a*, being within the condenser. It screws into the hole *a*, view (*c*), that opens into the passage *r* leading to the air-pump connection at the back of the lubricator. The equalizing tubes, as well as the steam pipe to the lubricator, have been enlarged so that a larger supply of steam will go to the oil pipes. The gauge glass *14* is provided with an automatic ball check-valve [a small ball *s'*, view (*c*)], in both the upper and lower gauge arms, that closes and prevents the escape of oil and water in the event of the glass breaking.

The by-pass valves *j* that replace the hand oilers on the other lubricators are intended for use only when oil cannot be fed through the feed-glasses, as, for instance, when a glass breaks; at all other times they should be kept closed tight so as to prevent a waste of oil. When a valve *j*, view (*a*), is opened, the oil passes directly from the oil reservoir *A* through the valve and out to the oil pipe, as indicated

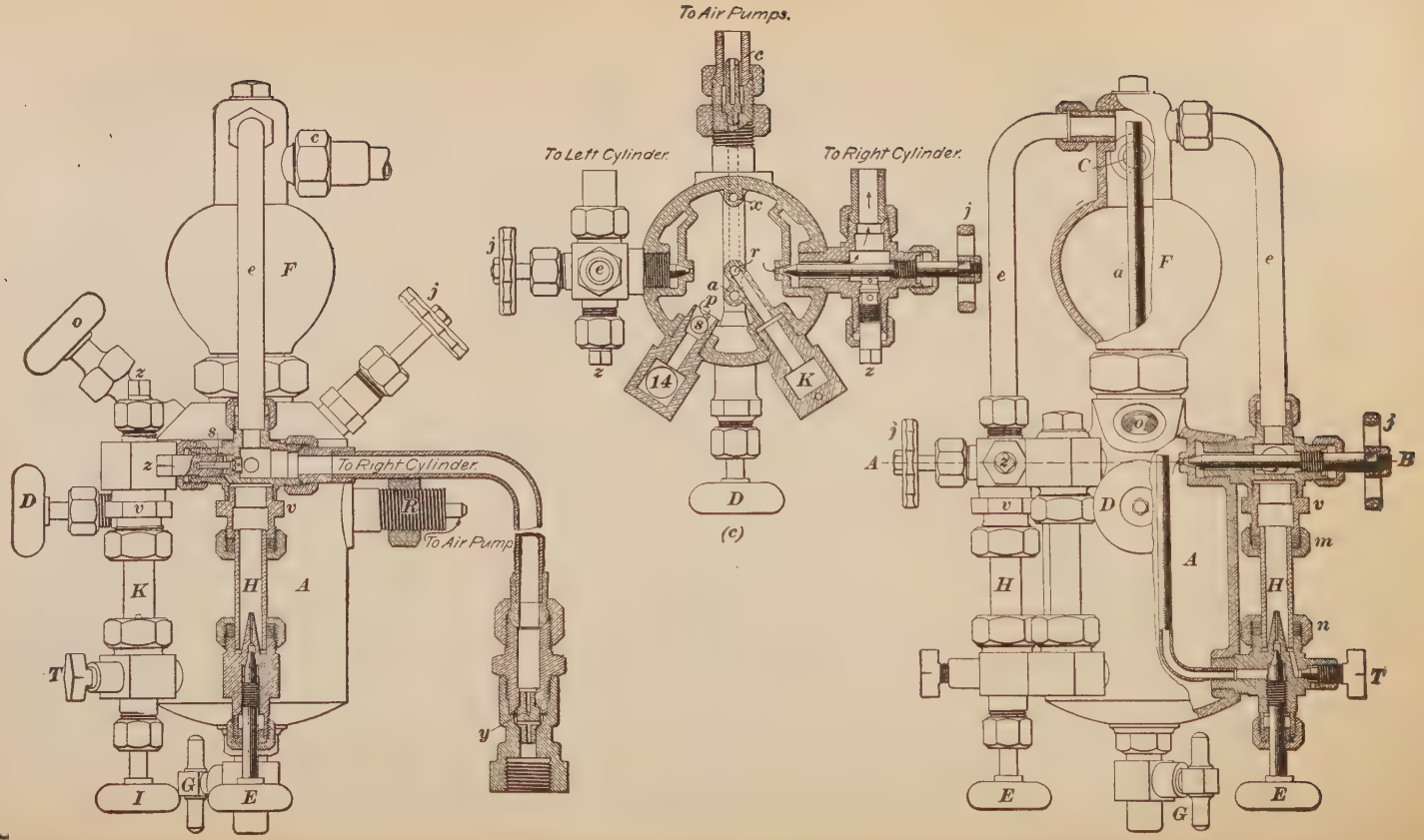

To Air Pumps.
To Left Cylinder.
To Right Cylinder.
To Right Cylinder.
To Air Pump.
To Air Pump.
(a)
(b)
(c)

FIG. 9

by the arrows. These valves are made to feed at the same rate as the regulating valves E for the same amount of opening; that is, if both are opened, say, one-eighth turn, they will feed at the same rate. Another advantage is that they feed continuously like the feed-valves, it not being necessary to shut off the engine to use them. Only one regular choke plug is used, that being in the air-pump connection, view (c). The cylinder oil pipes are supplied with a steam-chest plug that contains a check-valve y, view (b), which performs the duty of the choke valve. This valve has a $\frac{3}{32}$-inch hole through it and is movable. Their construction is such as to prevent their becoming inoperative through the lodgment of dirt or sediment at that point.

12. Operation.—The directions for operating this lubricator are the same as for the other. However, there are several additional points to be remembered with this lubricator.

To clean the glasses, open the valve T and unscrew the safety valve z sufficiently to make a direct opening between the feed-glass and the oil pipe, view (b). This will permit steam to blow through the equalizing tube past z and through the glass and valve T to the atmosphere. When the glass is clean, close the valve T, and as soon as the glass fills with water, screw z tight to its seat and leave it in that position. These valves should be kept closed when the lubricator is in operation.

To operate the by-pass valves, proceed as follows: Always keep them closed unless in use. In the event of a glass breaking, close its regulating valve E and use the by-pass valve for oiling that cylinder. Regulate the feed exactly as you would the regulating valve; that is, turn it the same amount in opening, as it will then feed the same. If it is opened too much, oil will be wasted just as it is if the regulating valve is opened too much.

To remove a glass, unscrew the gland nuts m and n and push the upper one down on the lower; then unscrew the sleeve v, push it down on the glass, and the glass can then be readily taken out.

To replace a glass, place the gaskets, gland nuts, and sleeve *v* properly on the glass and insert the glass; next screw the sleeve *v* to place and tighten the gland nuts.

THE DETROIT BULL'S-EYE LUBRICATOR

13. With the high steam pressures carried in modern locomotive boilers, explosions of the tubular glasses used in lubricators became such a menace to the safety and comfort of the men in the cab that the Detroit Lubricator Company devised a type of glass, of a disk or lens shape and known as the bull's eye, that would not explode in service.

The **Detroit No. 21** three-feed lubricator is different in arrangement from the older types, having fewer parts. Lubricators are made with from one to seven feeds, the double-, triple-, and four-feed lubricators being in most general use. The triple cup is shown in Fig. 10, (*a*) being the front view and (*b*) a side view; (*c*) is a front view of the four-feed cup.

14. The triple cups are illustrated in section in Fig. 11, (*a*) being a front view with the front half removed; (*b*), a side view; (*c*), another side view, showing the water passage *W* and its ball check-valve *5*; (*d*), a top view, partly in section, showing the equalizing passage *e* and the hand oiler passage *P* to the right-hand cylinder; (*e*), the steam-chest plug *22* complete with its valve *19*; (*f*), the details of the drain valve *6*; and (*g*), the sight-feed glass *10*, its packing sleeve *11*, rubber packing *12*, and the follower washer *13*.

1 is the body of the cup and the condenser, which are cast solid together, with the equalizing passages *e*, water passage *W*, oil passage *o*, and the sight-feed chambers *C*, cast with the body, and afterwards drilled out to the proper size, so that they are smooth and true inside. The plugs *30* are put in to fill the holes for the core used in casting the body, and are not removed after the cup is once in service.

2 is the filler plug, *3* the steam valve complete. *23* is a plug to fill the opening where the oil pipe *18* is screwed into the oil passage *o*; and *25* is a plug to close the opening in the top of the condenser. *6* is the drain valve to draw water

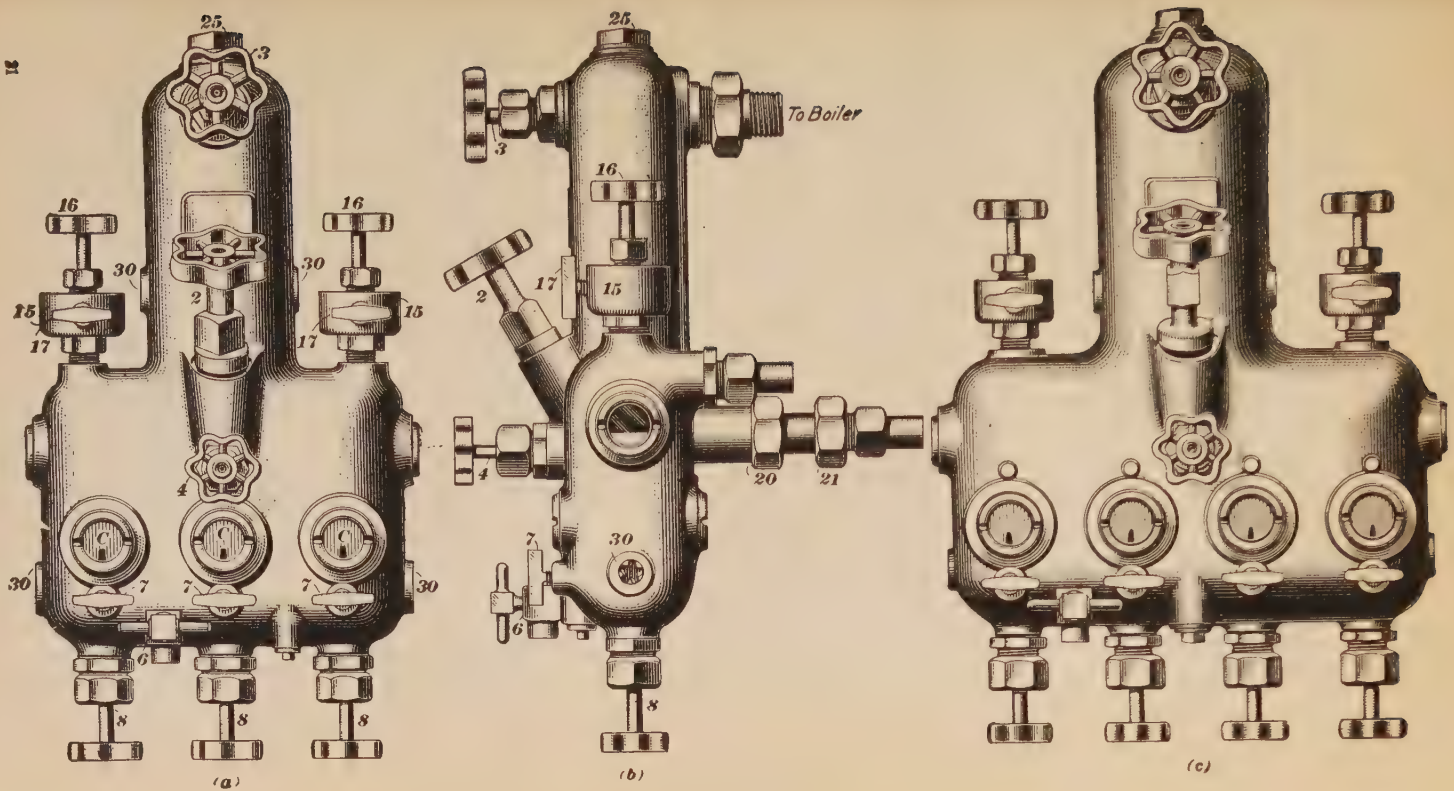
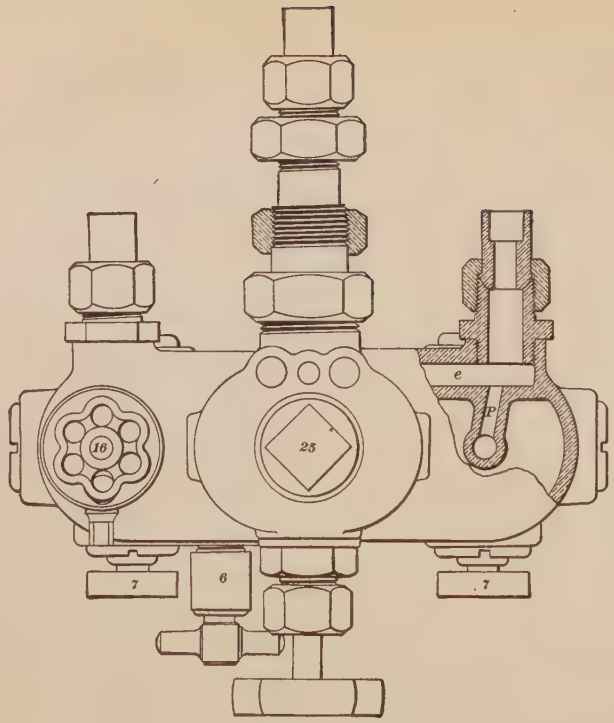

25
3
16
16
30
30
2
15
15
17
17
4
30
7
7
7
30
6
8
8
8
(a)
25
To Boiler
3
16
2
17
15
4
20
21
7
30
6
8
(b)
(c)

FIG. 10

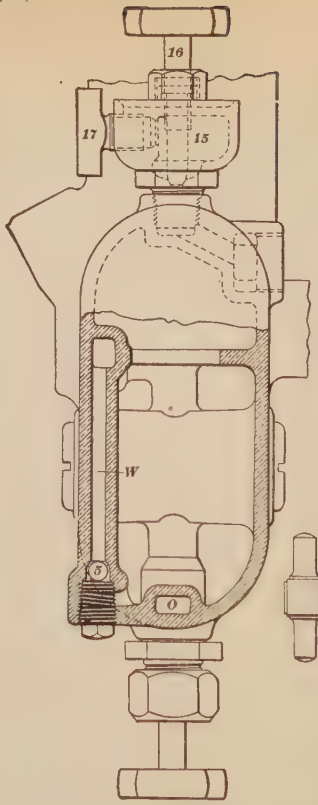
out of the oil tank when refilling the lubricator; *7* is the vent valve for draining and blowing out the sight-feed chambers *C* and clearing off the outside of nozzles *9*. The hand, or auxiliary, oil cups are shown at *15*; the hand oiler valve, at *16*; and the filler plug for this cup, at *17*. *22* is the steam-chest plug, complete, shown in Fig. 11 (*e*); it encloses a valve *19* that has a small opening crosswise through it and another opening from the end meeting the cross opening. When this valve is on its seat, as shown, the small opening serves as a choke to maintain the boiler pressure in the cup and in the oil pipe from the cup to the steam chest and thus insure that the feed of oil is regular, whether the engine is working steam or drifting. A similar valve is used in the air-pump oil passage, which is always the middle one of the three. This valve is not interchangeable with the steam-chest plug valve.

There are no choke plugs or restricted openings in the cup for the oil pipes to the locomotive steam chest; the steam-chest valves regulate the flow of steam through these pipes. The ball check-valve *5* in the bottom of the water passage *W*, Fig. 11 (*c*), is intended to prevent the water and oil siphoning out of the oil tank. The sight-feed glasses are shown at *10*, while the gauge glasses to show the amount of oil in the cup are at the top in each side. A reflector *14* is placed behind each glass disk in the top of the oil tank to better enable the amount of oil in the tank to be seen as it feeds out. The sight-feed nozzles *9* are screwed into the bottom of the sight-feed chambers *C* and can easily be removed when necessary. The method of fastening the sight-feed glass *10* and its packing ring *11* in the body is shown in Fig. 11 (*a*), and in (*b*) the one in the back part of the cup is removed to show the opening and the shoulder against which the glass rests. The follower *13* should not be screwed in very tight, as the pressure within the cup keeps the glass tight against the packing.

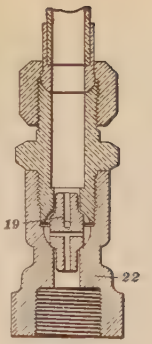
15. Automatic Steam-Chest Valves.—The automatic steam-chest valve *19* is shown in Fig. 11 (*c*). These valves



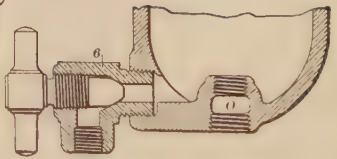
(d)



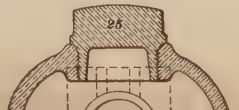
(c)



(e)



(f)



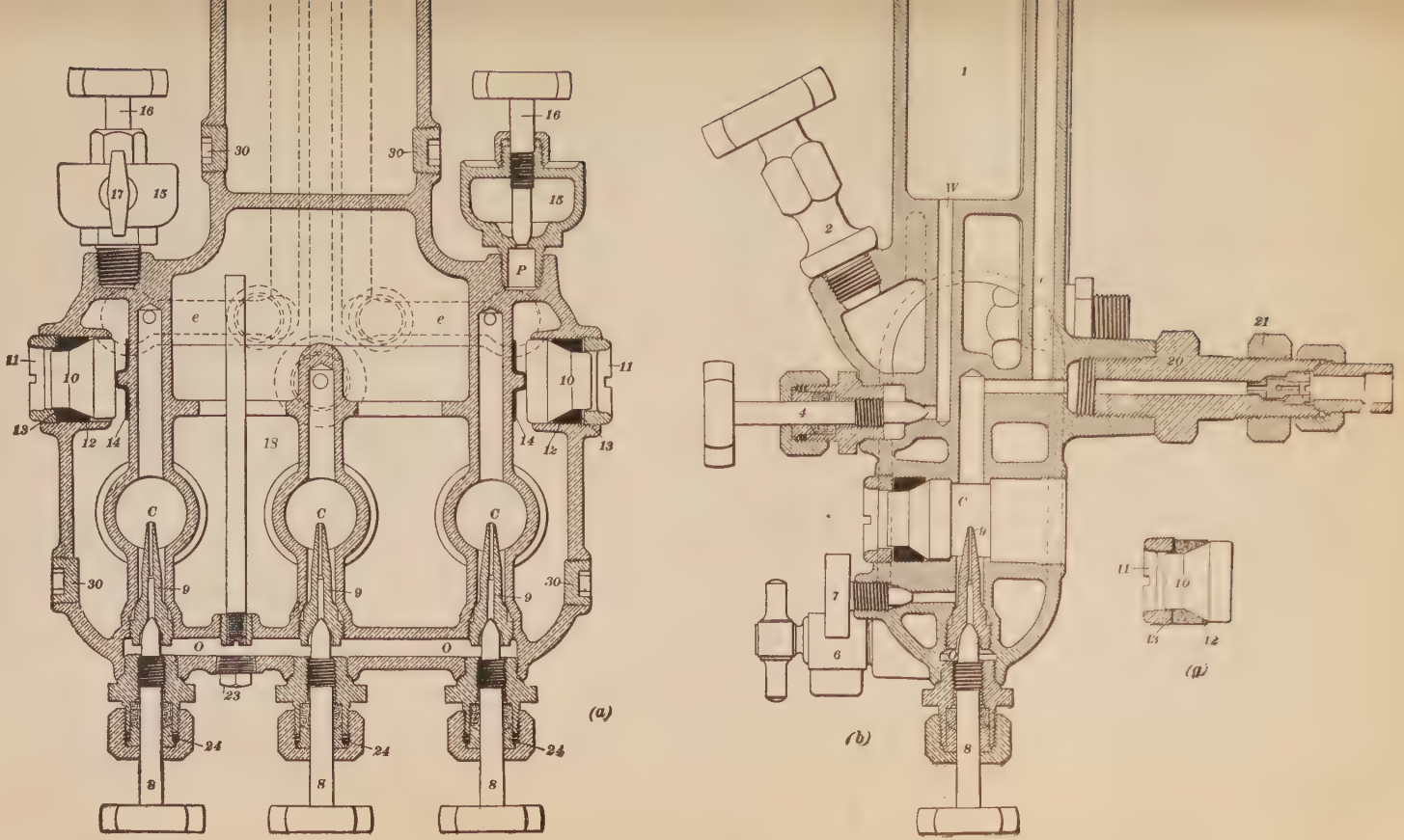


FIG. 11

are reversible and have about $\frac{3}{16}$ inch lift; this movement prevents any foreign matter remaining on the seats. The openings in these valves for simple locomotives and for the high-pressure sides of Vauclain, tandem, or cross-compounds, are $\frac{5}{64}$ inch; while those for the low-pressure steam chests, low-pressure cylinders, extension piston rods, or the piston-rod packing between the high- and low-pressure cylinders of a tandem compound are $\frac{1}{16}$ inch. The different sizes of chokes are necessary owing to the difference between the high and low steam pressures.

16. When the No. 31, or four-feed lubricator, Fig. 10 (*c*), is used on cross-compounds, the two outer feeds are intended for the high- and low-pressure steam chests. Two plugs are furnished—one $\frac{3}{32}$ inch, stamped *H. P.*, while the other is $\frac{1}{16}$ inch and is stamped *L. P.* The two inner feeds are intended for the intercepting valve and for the air pump; they have chokes at the lubricator as shown in Fig. 11 (*b*).

If these choke plugs get worn larger than the standard size, the cup will not feed regularly when steam is shut off, in which case new valves of the proper size should be put in or the valves changed end for end on their seats.

To clean out chamber *C*, open the vent valve *7*. To use the hand oilers *15*, see that valve *16* is closed, then open filler valve *17* and pour oil into the cup. Close the filler valve and open *16*, when the oil will pass into the oil pipe.

This cup is filled with oil the same as any lubricator and operated in the same manner.

MICHIGAN LUBRICATOR

17. Description.—In the Detroit and Nathan types, a choke plug is used in the discharge opening from the lubricator to the oil pipe leading to the steam chest. This plug restricts the flow of steam from the lubricator so that a pressure uniform with that of the boiler may be maintained in the lubricator at all times when it is working. Practically all locomotive-cylinder lubricators have this choke plug; in some of them it is located at the steam-chest end of the oil

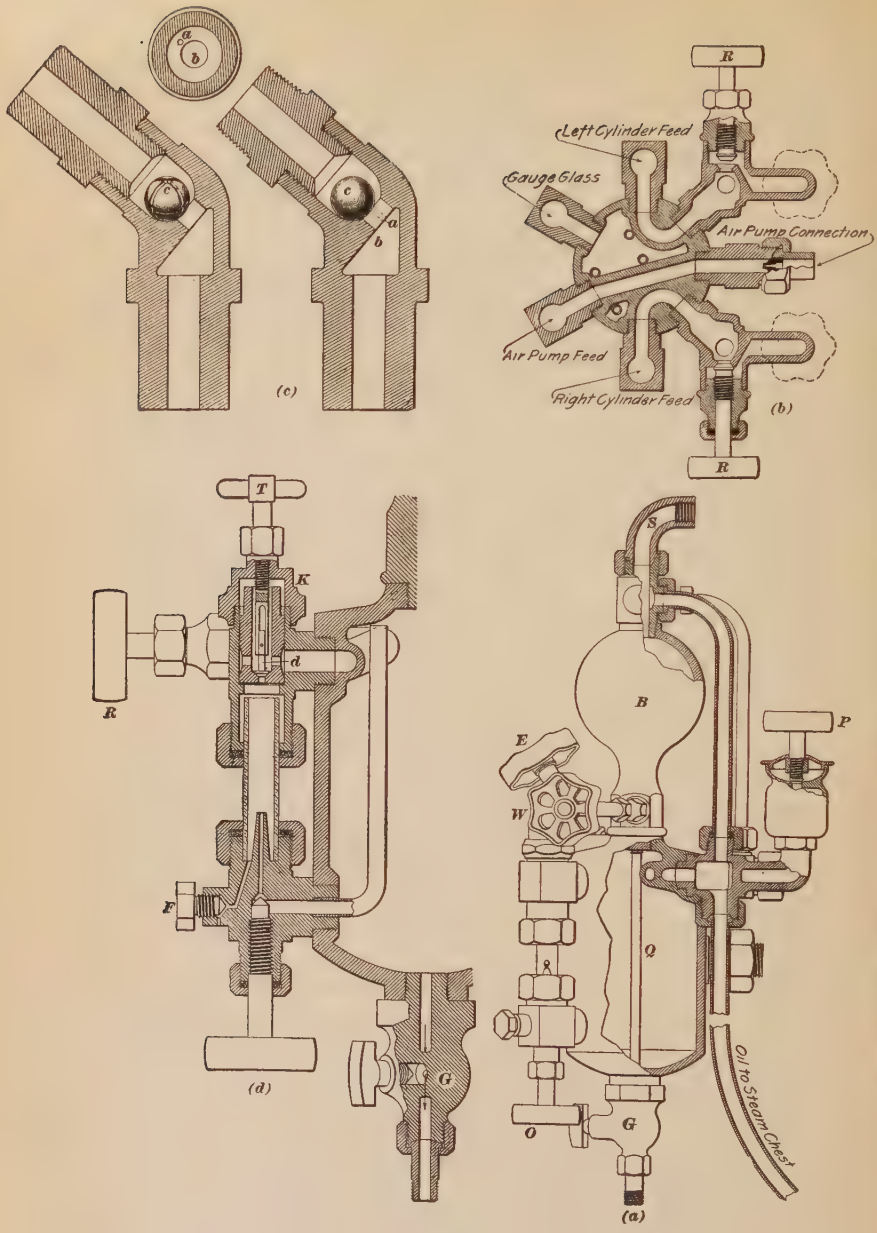

a
b
(c)
R
Left Cylinder Feed
Gauge Glass
Air Pump Connection
Air Pump Feed
Right Cylinder Feed
(b)
R
T
K
d
R
F
G
(d)
S
B
P
E
W
Q
R
O
G
Oil to Steam Chest
(a)

FIG. 12

pipe, instead of in the lubricator. In the **Michigan lubricator,** illustrated in Fig. 12, the openings that convey the steam and oil from the feed-glass to the oil pipes leading to the steam chest are not restricted in any way. On the contrary, they are somewhat larger than in the other types, both as regards the steam pipe leading from the boiler,* and also the steam passages in and around the oil reservoirs. The oil pipes leading to the steam chest are of the ordinary size.

In view (*a*) is shown the lubricator as a whole, with the exception that certain portions are removed so as to show the internal construction more clearly. View (*b*) is a horizontal section through the body of the lubricator, taken on the line of the upper feed-arms. View (*d*) represents a portion of the lubricator on a larger scale, this being done so as to show more clearly the various passages, valves, etc.

Referring to the various parts: *A* is the oil reservoir; *B*, the condenser; *E*, the filling plug; *F*, the gauge-glass drain cock; *G*, the drain plug; *K*, the cap for the removable plug that allows a new glass to be put in; *L*, the pipe that conveys oil to the feed-glass; *M*, the oil pipe, or "tallow pipe," as it is still often called; *O*, the regulating valve; *P*, the filling valve; and *R*, the feed-valve, for the auxiliary oiler; *Q*, the water pipe that carries the water from condenser to reservoir; *S*, the steam pipe from boiler; *T*, the lifting stem for check-valve *d*; and *W*, the water valve.

At the steam-chest end of the oil pipe *M* is a choke plug, two designs of which are shown in view (*c*). This choke plug, shown in the right-hand view on a larger scale than the lubricator itself, has two openings—a small one *a*, and a large one *b*. The small one *a* is open at all times. The large one *b* is intended to be open when the engine is working steam and the pressures are therefore equalized in the oil pipe and steam chest, and is to be closed by the ball valve *c* when the throttle is shut, or at any time that the pressure in the steam chest is much lower than in the lubricator. When the throttle is shut, the pressure being greater

*The steam-supply pipe *S* should have a bore of not less than ¾ inch.

in the lubricator and oil pipe than in the steam chest, the ball *c* rolls against its seat, closing the large opening *b*. The steam from the lubricator, carrying with it the oil, must then pass through the small choke *a*. When the throttle is open, or when the pressure in the steam chest has equalized with that in the oil pipe, the ball valve *c* drops from its seat and uncovers the large opening *b*, through which steam can pass from the lubricator. This ball *c* is also made with small grooves around it, which serves the same purpose as the choke *a*, the grooves being less liable to become choked. With this style of ball *c* the choke *a* is not used; this is shown in the left-hand view.

The auxiliary oiler, shown in view (*a*), has a hand valve *P* by which the cup *C* is filled, and a feed-valve *R* [see views (*b*) and (*d*)], controlling the opening from this cup to the oil pipe. To operate the auxiliary oiler, close the valve *R* and open the valve *P*, allowing any steam that may be in the cup *C* to pass out; then put in the oil, close the valve *P*, and open valve *R*, which permits this oil to pass into the oil pipe. There is an auxiliary oiler for each cylinder.

The automatic check-valve *d* at the top of the sight-feed glass, view (*d*), is secured to the lifting stem *T* by a pin that passes through the stem of the valve and works in a slot in the stem *T*. When the stem *T* is screwed clear up, it lifts the valve *d* off its seat and holds it off; when screwed down, it allows the valve *d*, to seat and unseat automatically. This check-valve prevents the passage of the steam or water back into the sight-feed in the event of a glass breaking. To fill the feed-glass with water, the valve *d* must be raised off its seat so as to allow condensed water from the equalizing tubes to flow into the glass and fill it.

The small drain plug *F* is to allow water, and (in case the glass is being blown out clean) steam also, to pass out of the glass.

18. Refilling and Operating.—To refill the reservoir, first close the regulating valves *O*, and then the steam valve and the water valve *W*. Fill through the plug *E*.

To operate the lubricator, open the steam valve full, admitting boiler pressure; then open the water valve *W*, and when the condenser and sight-feed glasses are full of water, start the feeds, regulating them by the valves *O*.

When leaving the engine after a run, close the valves *O* first and the steam valve last, leaving the water valve *W* open.

Some roads require that all valves be closed if the lubricator is not to be filled until just before the run. It is claimed that by closing the water valve the lubricator will be cool for filling and there will be no danger of the person filling the lubricator being scalded. If the lubricator is filled at the end of the run, the water valve must be left open so as to prevent the cup from being burst by the expansion of the oil.

THE MICHIGAN BULL'S-EYE LUBRICATOR

19. The **Michigan bull's-eye lubricator** is shown in Fig. 13, (*a*) being a side view in section, cut through the cup from top to bottom; (*b*), a front view of the cup as a whole; and (*c*), a rear view. This design of lubricator has a circular, or disk-shaped, glass, which will not burst as do the tubular glasses located in arms above the oil reservoir, so that the oil issues directly from the top of the reservoir, passes through the sight-feed chambers, and thence to the oil pipes. Referring to the various parts: *38* is the body of the cup or oil reservoir; *34*, the condenser; *31*, the steam-pipe connection from the boiler; *61*, the oil-pipe connections; *56*, the sight-feed glasses; *57*, the packing for these glasses; *57a*, the follower ring for this packing; *41*, the water valve; *42*, the oil regulating valve; *42a*, the oil nozzle through which the drops of oil feed upwards; *44*, the drain valve from the oil reservoir; *39*, the filler plug; *33*, the water pipe leading from the water valve to the bottom of the oil reservoir; *40*, the steam induction or equalizing tube; *50*, the caliduct or heating chamber; *51*, the observation, or gauge, glass to note the amount of oil in the reservoir; *54*, the packing for this glass; *55*, the tap bolts that secure the glass and packing to the body of the cup; *62*, the visible auxiliary oilers;

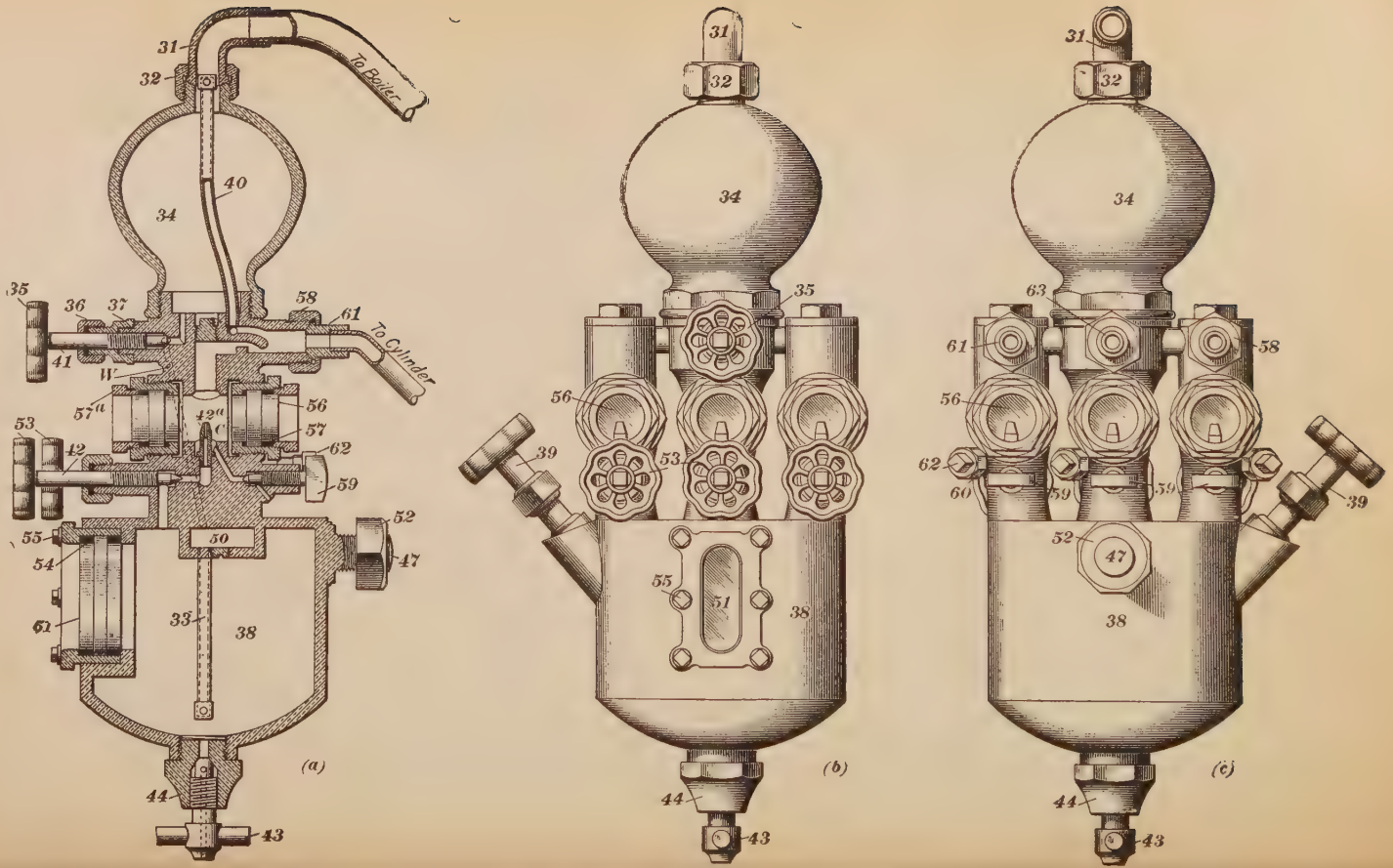

31
32
To Boiler
40
34
35
36
37
58
61
To Cylinder
41
W
57a
42a
C
56
53
42
57
62
59
52
55
54
50
47
61
33
38
44
43
(a)
31
32
34
35
56
39
53
55
51
38
44
43
(b)
31
32
34
63
61
58
56
62
60
59
59
39
52
47
38
44
43
(c)

Fig. 13

47, the support arm by which the cup is fastened to the boiler bracket.

Live steam from the boiler enters at the steam connection *31*, part of it condenses and keeps the condenser *34* full of water up to the opening at the top of the steam equalizing tube *40*. Condensed water flows past the water valve *35*, when open, through the passage *W* shown in dotted lines into the caliduct, or heating chamber, *50* cast in the top of the oil reservoir and then through the water pipe *35* to the bottom of the cup. This flow of hot water is intended to keep the oil warm.

Live steam passes down the tube *40* and into the top of each sight-feed arm and into the oil passage from the top of the sight-feed chambers *C*. This current of live steam keeps the chambers *C* full of condensed water and carries the oil as fast as it rises from the oil nozzles *42ª* through the water in *C*, on into the oil pipes and thence to the steam chests; the middle oil-pipe connection leads to the air pump and has a choke of $\frac{3}{64}$ inch opening. The oil-feed nozzles *42ª* are shown in view (*a*), also the sight-feed glasses and the manner in which they are put in with the packing rings. These glasses are in a casing separate from the body of the cup. The threaded follower *57ª* holds the packing against the glass and makes a tight joint. The observation glass *51* is made tight with packing rings and held solid with six tap bolts *55*. This glass has an aluminum reflector back of it in the oil reservoir to show the height of the oil better.

The visible auxiliary oilers *62* are valves which, when turned to open, allow oil to pass directly from the oil reservoir into the sight-feed chambers *C*, where it can be seen raising and passing to the oil pipes.

The steam-chest plug and ball choke used with the bull's-eye cup is the same as the one used with the other Michigan lubricators. It is shown in Fig. 12 (*c*). There are no chokes in the oil pipes to the steam chest at the lubricator.

This cup is filled and operated the same as any other design when feeding oil through the sight-feed regulating

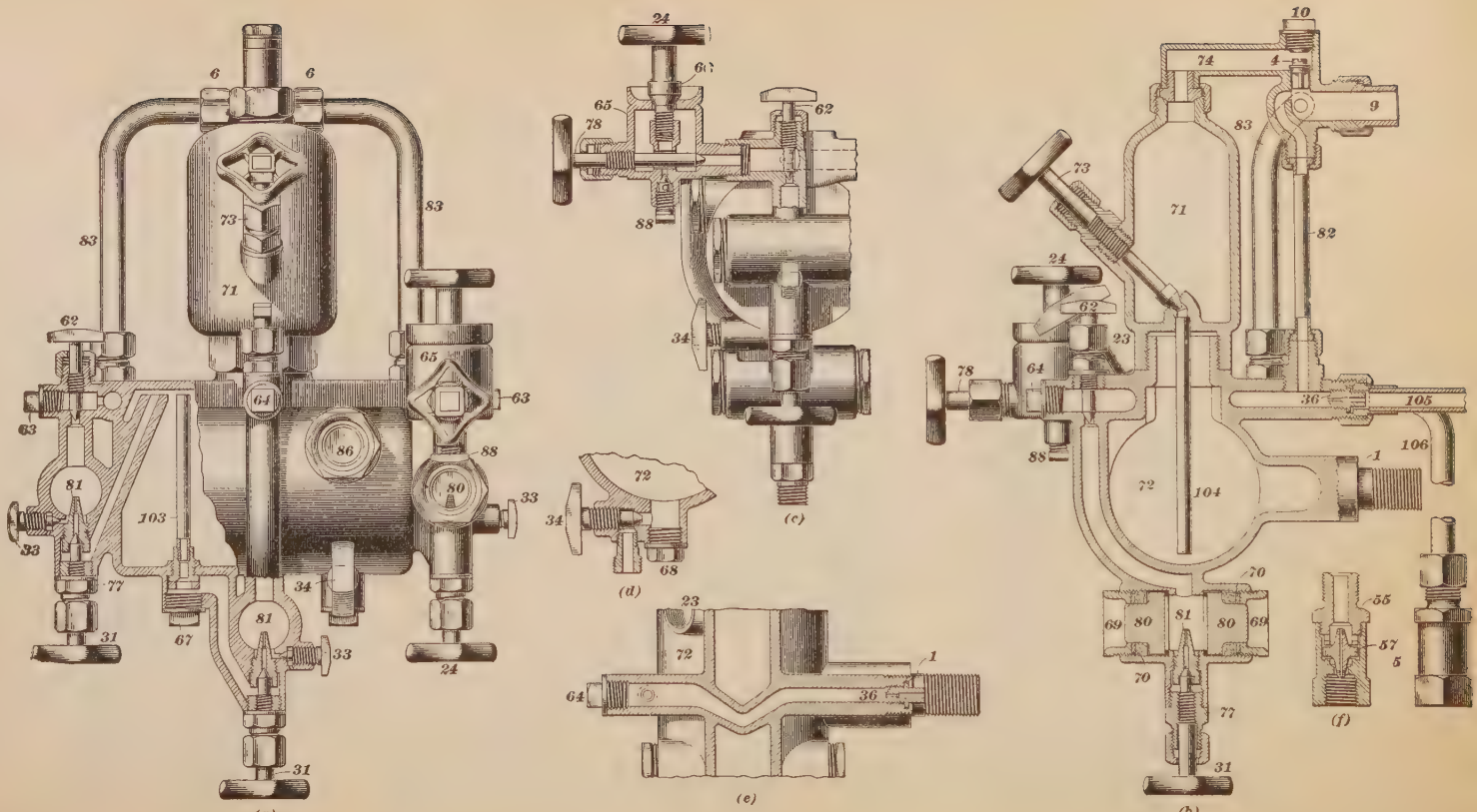


FIG. 14

valves. When the visible auxiliary oilers are used, turn plug valve *62* open a little; as soon as sufficient oil has passed out through the chamber *C*, close valve *62*.

THE CHICAGO LOCOMOTIVE LUBRICATOR

20. Description.—The **Chicago locomotive lubricator** with bull's-eye or solid sight-feed glasses is manufactured in three styles: *Class C with three feeds*, two for the steam chests and cylinders of the engines and one for the air pump, *class D–3 with four feeds*, and *class C with five feeds*. The latter style is for use on compound locomotives where more than two feeds are necessary to supply oil to the high- and low-pressure cylinders. With tandem and balanced compounds, each of the four cylinders requires a separate feed; on any locomotive, the air pump usually has a separate feed. In the case of cross-compounds, one feed is usually required for the intercepting valve.

Fig. 14 (*a*) shows a front view of the **class C three-feed lubricator** with the left side sectioned vertically, showing the details of one of the sight-feed arms with its oil passage from the oil bowl to the regulating valve and passage to the oil pipe, and the oil passage to the air-pump sight feed with the details of its arrangement. Fig. 14 (*b*) shows a side view of the cup sectioned vertically through the center; (*c*), a sectional view of the auxiliary oil cup; (*d*), a sectional view of the drain plug of the oil bowl; (*e*), a sectional view of the cored passage across the top of the oil bowl that conducts the oil to the air pump; and (*f*), a sectional view of the complete steam-chest valve.

21. Construction.—In Fig. *14*, *4* is a check-valve that will admit steam from the boiler to the condenser while the boiler valve is open, but will not allow any steam to pass back, thus preventing the contents of the condenser from siphoning out; *6*, is the equalizing-pipe connection nut to the steam head; *9*, a steam pipe from boiler; *10*, a plug in the steam head over the check-valve *4*; *23*, filler plug; *24*, hand wheels for turning valve spindles; *31* regulating or feed-valve; *33*,

drain valve for sight-feed chamber; *34*, drain valve for oil bowl; *36*, air-pump choke; *55*, steam-chest valve cap; *57*, steam-chest valve; *62*, pressure valve; *65*, auxiliary oil cup; *66*, auxiliary oil-cup filler plug; *69*, packing nut for glass; *70*, follower ring for glass; *71*, condenser; *72*, oil bowl or reservoir; *73*, water valve; *74*, steam head or connection to condenser; *77*, sight-feed-valve hub; *78*, auxiliary oil-cup valve; *80*, sight-feed glasses; *81*, sight-feed oil nozzle; *82*, equalizing pipe for air-pump feed; *83*, equalizing pipe for cylinder feed; *86*, index glass; *88*, auxiliary oil-cup drain plug; *103*, oil pipe to air-pump feed; *104*, water pipe from condenser. The plugs *63*, *84*, and *67* are put in to close up openings in the lubricator.

22. Operation.—After the oil bowl *72* has been filled with oil at the filling plug *23* and steam has been turned on at the boiler into steam pipe *9*, it passes into the condenser *70*, which fills with condensed water. Steam passes down the equalizing pipe *82* to the air-pump feed and equalizing pipe *83* to the steam-chest oil pipes. If the pressure valves *62* are open, this steam will also fill the sight-feed chambers between the glasses with condensed water. Water valve *73* being opened, the pressure or the head of water in the condenser is then exerted on the oil in *72*, which tends to force it to the top of *72* and down the pipe *103* to the air-pump feed-valve [see Fig. 14 (*a*)]; also through the oil passage drilled through the casting leading to the regulating valves for the cylinder feeds. When the feed-valve *31* is open, oil can pass by it upwards through the oil nozzle *81*. As it slowly feeds by the feed-valve, it forms a small globule of oil, or *drop*, as it is termed, and gathers on the tip of the nozzle *81*, where it is surrounded by water and in plain view through the glasses *80*.

When this drop reaches sufficient size so that its buoyancy pulls it loose from the tip of the nozzle, it floats up through the water passing the pressure valve *62*, through the passages in the top of the oil bowl, and into the oil pipes leading from the cup. The oil from the air-pump feed goes up through a cored passage around the front of the oil bowl,

shown on the left-hand side of Fig. 14 (*b*), and then across the top of the oil bowl through the cored passage shown in Fig. 14 (*c*). This cored passage is deflected to one side to clear the water pipe *104* when the condenser *71* is screwed down on top of *72*. It is necessary to have this water pipe extend down to the bottom of the oil bowl so that water can get down without allowing the oil, which floats above the water, to get up into the condenser. When steam from the boiler comes into the condenser, it gives its pressure to the water there and through the water pipe *104* to the oil in the oil bowl, so that, unless this pressure of the steam was balanced at the oil pipe leading from the cup, the oil would be forced out of the cup in short order. To balance the steam pressure on that side of the regulating valves *31*, the equalizing pipes *82* and *83* are used. Through these pipes, the boiler steam has access to the oil passages and feed-valve chamber; as the opening away from these oil passages to the air pump and steam chests is restricted, the steam can come in through the equalizing pipes faster than it can get out of the oil passages, and this maintains the pressures equal in the condenser and in the oil passages above from the sight feeds. With the steam pressures balanced, the pressure on the oil due to the head of water in the condenser is the only pressure that tends to force oil past the regulating valves; as the head of water in the condenser remains constant while the cup is working, the feed of oil will remain steady.

23. To restrict the flow of steam from the cup, there is a choke *36* in the air-pump passage. As the air pump is usually working steam when the locomotive is in operation, and the pressure in its steam pipe is somewhat less than boiler pressure, this choke suits the conditions there.

With the oil pipes to the steam chests of the engines, the conditions are different. When the engines are working steam at a short cut-off and boiler pressure is nearly that in the steam chests, there is very little difference of pressure between the steam chest and the passages in the cup. When the engines are working under check with a moderate share

of the boiler pressure in the steam chest there is considerable difference between pressure of the steam chest and the cup. When the locomotive is drifting with steam shut off, there is a partial vacuum in the steam chests and this makes the pressure still more unequal.

To equalize the pressures in the cup or both sides of the feed valve and to provide for a steady flow of the oil that has passed the feed-valves, a steam-chest valve *57* is placed at the opening into the steam chest. This restricts the flow of steam away from the cup when the engine is drifting or is working steam at a moderate proportion of the throttle opening and the pressure is less in the steam chest than in the oil pipes. At such a time, the valve *57* is resting on its seat in the body, so that the only passage for the steam and oil is through the restricted opening in the valve *57* from the top to the bottom. This maintains the flow of steam and oil away from the cup at a regular feed and the cup will not feed any faster when the engine is drifting than when working steam. When the steam-chest pressure is equal to or greater than the pressure in the cup, the valve is moved up from its seat and gives a larger opening than when resting on its seat. This valve is reversible, and can be used either end up.

Placing a steam-chest valve at the end of the oil pipe next to the steam chest virtually makes the oil pipes a part of the cup, giving a free passage from the sight-feed chambers, so that there is nothing to interfere with the regular and steady flow of the oil from the sight-feed nozzle *81* to the steam chest.

24. Operating the Lubricator in Service.— To fill the cup, shut off the feed valves *31* and the water valve *73* and open the drain valve *34*. As soon as sufficient water has run out of the cup to reduce the pressure, open the filling plug *23*. When the water is all drained from the oil bowl *72*, close drain valve *34*. Fill the oil bowl full of oil and close the plug *23* tight. The air space in the top of the bowl around pipe *104* and next to the condenser [see Fig. 14 (*b*)] will prevent the cup from bulging provided it is

filled with cold oil and then heated. To start the lubricator, see that the valve at the boiler is wide open, open the pressure valve *62* one turn, and the water valve *73* three turns. See that the sight-feed chambers between the glasses *80* are full of clean water; after which open feed-valves *31* to regulate the supply of oil passing these valves. Be sure that the condenser has time to fill with water before opening the feeds.

To blow out the sight-feed chamber close feed-valve *31* and pressure valve *62*. Then open the drain valve *33* and exhaust the pressure, after which regulate the flow of steam for blowing out with valve *62*. When blown out clean, close valve *33* and open valve *62* one turn. To blow out the nozzles *81*, close the water valve *73* and open regulating valve *62*; with steam on the cup, open the drain valve *34* and the contents of the sight-feed chamber will be blown through the nozzle into the oil bowl. To use the auxiliary cup *65* when the engine is working steam, close pressure valve *62* on that side and see that the auxiliary feed-valve *78* is closed; then open drain valve *88* to drain the auxiliary cup and open the auxiliary filler plug *66*; when the cap is drained, close drain valve *88* and fill the cup. Close valve *66* and open valve *78* wide. This auxiliary cup can be operated in this way with steam on the lubricator. The pressure valve *62* should be closed when using the auxiliary cup.

To slush the engine when drifting or standing with steam shut off and with the lubricator feed-valve *31* set at the regular supply, close the steam valve at the boiler for a second or two. This will reduce the pressure in the oil passages, and the check-valve *4* will hold the pressure in the condenser and oil bowl. After sufficient oil is delivered to the oil pipes, open the steam valves wide. This will balance the pressures in the cup and the feed will be at the same rate as before.

25. To Renew the Glasses.—The position and arrangement of the glass *80*, its washer *70*, gasket and packing nut *69*, are plainly shown in Fig. 14 (*b*). A washer is put in the body next to the sight-feed chamber, and then the glass with its gasket on is inserted large end first; put the follower ring

in place on the gasket and screw in the packing nut *69* until the proper resistance is felt. Close pressure valve *62* and open drain valve *33* when taking out a sight-feed glass. To change an index glass *86*, the oil bowl must first be emptied.

26. Class C 5-Feed Lubricator.—With the **Class C 5-feed lubricator**, the parts below the joint where the condenser joins the oil bowl are identical with class C with three feeds. The additional feeds are connected to or are a part of the condenser and are shown in Fig. 15 (*a*), (*b*), and (*c*). Fig. 15 (*a*) shows the condenser *90* with the steam head *91*, which has two more equalizing pipes *93*. Cast in with the body of the condenser in the same manner as shown in Fig. 14 (*a*) are the two additional bodies for the sight-feed glasses with the nozzles, oil passages, drain valves, and pressure valves the same as there shown. The feed-valves shown in Fig. 15 (*c*) are in the bottom part of the condenser; the supply of oil comes up from the oil bowl through the port *a*; after passing the feed valves it flows through *b* into *c*, which is under the sight-feed nozzle *81* [see Fig. 15 (*d*)]. From there, it passes up through the sight-feed chamber by the pressure valve *62* and into the low-pressure-cylinder oil pipe in exactly the same manner that the oil passes out of the three-feed cup. It is operated in the same manner as the lower part of the cup in all respects. The illustrations give a complete idea of its construction.

LUBRICATOR TROUBLES

27. Choked Feeds, Etc.—Trouble is sometimes occasioned by the stopping up of the *sight-feeds* or the *choke plugs*.

Choked Feed Nozzle.—When a sight feed is found to be stopped up, close the regulating valves on the other feeds; next close the water valve that regulates the opening between the condenser and the oil reservoir; open the check-valves over the sight-feed glasses, where such are provided, and then open the drain cock at the bottom of the reservoir. If the steam valve is open, steam will blow through the equalizing tube into the feed-glass and force the contents of the

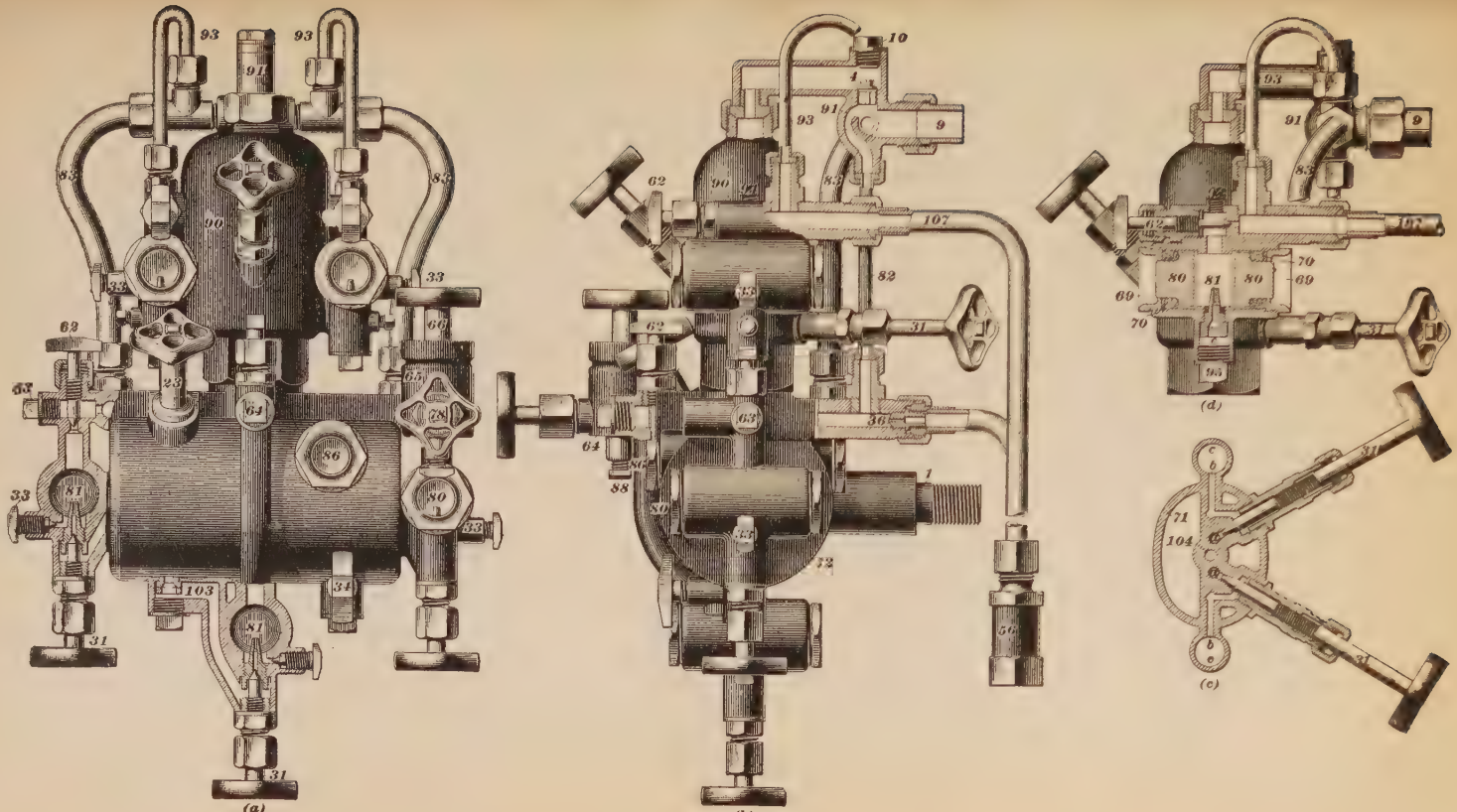


FIG. 15

sight feed, including the obstruction, into the oil reservoir, after which the drain cock should be closed. The regulating valve should then be shut until the feed-glass refills with water when the feed will be found to work all right. As soon as the drain cock is closed, the water valve should be opened and the other feeds may then be started.

When the feed glasses contain muddy water, they may be emptied in the same manner. Modern lubricators are provided with sight-feed drains for this purpose.

To blow out the sight-feed glasses on a Michigan lubricator, the plug *F* must be removed, and the valve *d* lifted off its seat by unscrewing the stem *T*; after the glass has been blown out and refilled with water, the stem *T* should be screwed down to allow the check-valve *d* to come to its seat.

Stopped-up Choke Plug.—If a choke plug in a lubricator becomes stopped up, close the steam valve to the lubricator and open the throttle on the engine. Steam pressure will then back up from the steam chest through the oil pipe and blow the obstruction into the feed-glass. It may sometimes be necessary to drain the water glass by opening the sight-feed drain, thus making a direct opening to the atmosphere. Where a lubricator is not provided with a sight-feed drain, open the sight feed on the glass having the choked plug, drain some water from the oil reservoir, and open the engine throttle.

The check-valve in the Detroit and Michigan lubricators, if acting properly, will seat itself as soon as the steam valve is closed. So in these cases, the oil pipe should be uncoupled from the feed-arm and the choke cleaned by hand.

28. Replacing a Broken Feed-Glass.—Should a feed-glass break on a Nathan lubricator, first close the regulating valve at the bottom of the broken glass, then the safety valve at the top, and use the auxiliary oiler until the glass can be replaced. To replace the glass, close the water valve and then the steam valve; take off the packing nuts on the feed-glass, and unscrew the valve box of the safety valve above that glass. The new glass may now be dropped in from above, through the packing nuts. Use new gaskets, and do

not tighten the packing nuts too much at first, or another glass may be broken. The valve box should now be replaced, and the steam and water valves opened; as soon as the glass fills with water the feed may be restarted. If it is desired to start the feed at once, the blow-off plug *5a* may be removed and the glass filled with clean water.

When a tubular glass breaks on a Detroit lubricator, close the regulating valve; the safety valve *s* is supposed to close automatically. To replace the glass, close the water valve and steam valve; open the drain cock, and draw enough water from the reservoir to allow the oil to drop below the top of the oil tubes; take off the packing nuts and unscrew feed-valve box *J* from the lower feed-arm; insert the glass from the bottom and use new gaskets to make tight joints; then replace the valve box in the lower feed-arm. The glass will probably have to be filled with water by unscrewing the plug *T* and filling by hand. The steam and water valves may then be opened gradually and the feeds started when the glass fills with water.

When a glass breaks on a Michigan lubricator, close the regulating valve; the check-valve *d* is relied on to close automatically. To replace the glass, close the steam and water valves, take off the cap *K*, and remove the plug that has the check-valve *d* in it; this will allow a new glass to be put in from the top—see Fig. 12 (*d*).

29. Irregularities of Feed.—Irregular feeding can generally be traced to one of three causes:

1. *Passages too Small.*—The passage through the steam valve, or the bore of the steam-supply pipe, may be too small. Either fault will prevent the lubricator from receiving full boiler pressure. This will be indicated by the lubricator feeding faster when the engine throttle is closed than when it is open. To see the effect of the above causes on the working of the lubricator, partly close the steam valve and note the feeds as the cut-off and position of throttle are changed. The steam valve should always be wide open while the feeds are operating.

2. *Equalizing Tubes Partly Stopped Up.*—This reduces the pressure above the water in the feed-glasses and the equalization is destroyed. At times when the steam-chest pressure is less than boiler pressure, the pressure acting to force the oil through the feed-valves is increased, and as a result the feed works too fast and the oil tends to enter the feed-glass in a stream, instead of forming in drops. If the equalizing tubes were wholly stopped up, steam pressure would be cut off from the top of the feed-glass when the engine throttle is closed, and the net force acting to send the oil through the feed valves would equal the boiler pressure plus the pressure due to the head of water. Under such conditions, the oil would squirt into the feed-glass if the feeds were opened though very slightly. It is seldom, however, that trouble is experienced from the equalizing tubes choking or stopping up.

3. *Choke Plugs Loose or Worn Too Large.*—The choke plug (marked 5 in the Nathan and *c* in the Detroit) is a small metal plug that is screwed into the upper feed-arm and opens into the oil pipe, as shown. It has a small hole (about $\frac{1}{32}$ inch in diameter) drilled in it, through which the oil and steam pass to the oil pipe. A choke plug is necessary, for, if the oil-pipe opening were not thus contracted, the fluctuation of pressure above the water in the feed-glass, every time the engine throttle or reverse lever is moved, would cause the feed to be extremely irregular. When a choke plug is used, it permits only a small flow of steam to escape into the oil pipe, and, consequently, the boiler pressure can be more nearly maintained, both in the condenser and in the feed-glasses. The opening in a choke plug must bear a certain relation to the quantity of steam delivered through the equalizing tubes, and if this is disturbed by the opening in the choke plug wearing larger, the feed will be irregular and will increase when the steam-chest pressure is decreased. The only remedy for this is to replace the worn-out plug with a new one having an opening of the proper size. A partly stopped-up equalizing tube will produce the same effects as a worn-out choke plug. In the improved Detroit lubricator,

Fig. 9 (*b*), if the port through the choke at the steam-chest wears greater than $\frac{3}{32}$ inch, it will cause the feed to be irregular, the same as worn choke plugs at the lubricator.

If the throttle is opened while the steam valve on the lubricator is closed, the water in the sight-feed glasses will become dirty. The reason for this is that, as there is no pressure in the lubricator, steam passes from the steam chest through the oil pipes and choke plugs into the feed-glasses, and carries with it dirty water and oil from the oil pipes. Whenever the sight-feeds become muddy, therefore, it indicates that for some reason the pressure in the lubricator is less than steam-chest pressure, and the cause should be ascertained and remedied.

30. Loss of Oil.—In some instances, the oil has been known to disappear mysteriously from the oil reservoir when the feed-valves were closed, but the water and steam valves open. This is usually found to be due to some mechanical defect in the lubricator. Some defects that have been known to cause the loss of oil are:

1. *Defective Casting.*—A small blowhole may exist in the casting, forming a passage from the oil reservoir into the condenser, or the upper feed-arm; in such a case the oil is forced through the blowhole and disappears. In the improved Detroit cup, Fig. 9, a blowhole anywhere in the passage connecting with passages *r* and *x* will allow the oil to leak from the cup into the air pump.

2. *Defective Water Pipe.*—The water pipe that leads from the condenser to the bottom of the oil reservoir may be split, or may make a poor joint where it screws into the water passage in the casting; in either case the oil will float into the condenser and disappear.

3. *Leaky Plug.*—The plug *20* in the Nathan lubricator, Fig. 3 (*c*), through which the oil pipe *22* is inserted, may permit the oil to leak through into the condenser.

4. *Leaky Packing.*—If the bottom feed-glass gaskets in a No. 2 Detroit lubricator are not tight, the oil will pass into the sight-feed chamber and then into the oil-pipe glass.

5. *Leaky By-Pass Valves.*—In the improved Detroit lubricator, the by-pass valves *j* may be leaking.

Cases have been reported where the oil has been siphoned out of the lubricator when the regulating valves were closed, the water and steam valves open, and the boiler allowed to cool down. In the modern lubricator, however, it is hardly probable that the oil can be siphoned in this manner, and any disappearance of oil can, in almost every instance, be traced to some mechanical defect.

31. Oil Held in Pipes.—Generally there are two forces acting to carry the oil through the oil pipes from the lubricator to the steam chests; namely, the force of gravity, which is constant, and the flow of steam, which fluctuates; the latter is usually flowing in greater or less quantities through the oil pipes. If the oil were to be carried along by the force of gravity alone, its flow would be slow and sluggish, and for that reason the flow of steam is supplied to accelerate its movements. The circulation of steam between the lubricator and the steam chest depends, of course, on the difference in pressure between the two places, the size of the steam pipe from the boiler, and the area of the opening in the choke. It is greatest when the throttle is closed, and it decreases gradually as the throttle is opened; the rate of flow of the oil through the pipes, therefore, varies correspondingly. If the throttle is open and the cut-off short enough to maintain the pressures in the steam chest and oil pipes equal, the circulation of steam through the oil pipes ceases, and the oil is carried onwards by the force of gravity alone.

32. Flow of Oil to Steam Chest.—Until the introduction of the small choke plugs to regulate the flow of steam from the lubricator, it seems that but little trouble was experienced in keeping the valves properly oiled. When high pressures came into use, it was noticed that, when working with wide-open throttle and short cut-off, the valves apparently received no lubrication, although with a long cut-off and partly closed throttle no trouble was experienced in

oiling them. This was at first attributed to the increase in working pressure, but later it was found that the increased pressure was not the cause, and that the trouble was also present with lower pressures, though much less noticeable. To determine the source of the trouble, the following experiment was performed: A glass tube similar to a glass water gauge was connected to the oil pipe in such a way that the oil and steam from the lubricator had to pass through the glass just before entering the steam chest. This glass therefore afforded a means of investigating the action of the steam and oil in the oil pipe during variations of pressure in the steam chest.

The experiment showed that with the small choke used at the lubricator, while the throttle was closed the oil and condensed water passed freely into the steam chest, through the oil pipes, but that when the throttle was opened, the glass and entire oil pipe began to fill up from the steam-chest end with water, on which the oil of course floated, and was thus prevented from reaching the steam chest. The reason for this was soon found to be because there was a large opening at the steam-chest end of the oil pipe and a very small one at the lubricator end. Therefore, when the throttle was opened and the steam-chest pressure was quickly raised, the oil pipe filled with condensed water and steam from the steam chest before it could fill through the choke. As soon as a sufficient difference of pressure was established between the lubricator and the steam chest, by easing off or entirely closing the throttle, the oil and water were at once forced into the steam chest. In the tests, it was observed that when steam-chest pressure was increased above 60 to 65 per cent. of the boiler pressure, the oil pipe began to fill with water from the steam chest, and thus retain the oil in the oil pipes; consequently, the valves would receive no oil as long as steam-chest pressure was greater than 65 per cent. of the boiler pressure. This, then, not only explains why the valves of an engine work hard after the engine has run for a time with wide-open throttle and short cut-off, but it suggests that under such circumstances

relief may be obtained by reducing the steam-chest pressure below the oil-pipe pressure for a few seconds, so that the oil entrapped in the pipes will be discharged into the steam chest and oil the valves and cylinders. This may be accomplished by partly closing the throttle for 4 or 5 seconds. Of course, this does not prevent the oil from again being held in the pipes, but it offers a means of getting oil to the valves whenever they begin to work dry.

In all the later makes of lubricators the idea has been to maintain boiler pressure in the oil pipe, the same as in the lubricator. The choke has either been placed at the steam chest, leaving the passage unobstructed from the equalizing tubes to the steam-chest choke, or an additional choke has been put in at the steam chest. With the choke at the steam chest, the oil will pass regularly through the oil pipes to the choke; the distance from the choke to the chest is so short that the oil will not be held there when the throttle is opened. Some of these steam-chest chokes have a variable opening—a large one when working steam in the engine and a small one when shut off. Others have a fixed size of opening.

LOCATION OF LUBRICATOR

33. The best location for the lubricator depends on the type of boiler and the position of the other cab fittings. When possible, it should be placed in such position that both the engineer and the fireman can see it plainly, as then any irregularities in its working are more liable to be readily noticed. If the engineer's seat is back of the boiler, the best location for the lubricator will be on top of the boiler at the end. When the engineer's seat is at the side of the boiler, the lubricator should be placed with the two engine cylinder feed-glasses in line with the boiler, and the air-pump sight feed and the oil gauge glass facing the engineer. Then, if a gauge light is placed on the lubricator bracket, the feeds will be in plain sight both day and night. The bracket that carries the lubricator should be strong enough to prevent vibration, as this tends to loosen the tubes and joints, making the action of the lubricator irregular.

The lubricator should not be located where the draft from an open cab window will cool it so that the oil will not flow freely through the oil passages.

PIPING FOR LUBRICATOR

34. The piping of a lubricator is a very important consideration; it is frequently the cause of irregularities in the working of the lubricator, for which the latter is wrongfully blamed. It is of the utmost importance that full boiler pressure be maintained in the lubricator, and anything that prevents this will cause the action of the lubricator to be irregular. The steam pipe to the lubricator, therefore, should be large enough to maintain boiler pressure there under all conditions; and, to obtain the best results, the opening in the pipe, steam valve, and fittings should be fully $\frac{1}{2}$ inch in diameter throughout.

The steam connection of the lubricator was formerly made at the turret. This is poor practice, however, as the pressure at that point fluctuates considerably, and full boiler pressure cannot, in consequence, be maintained continuously in the lubricator. To avoid this, the steam connection may be made to the highest point of the boiler inside the cab, and a dry pipe used.

To obtain the best results, the oil pipes and union connections should be of the same inside diameter throughout; the pipe should have a steady slope from the lubricator to the steam chest, so that, if necessary, the force of gravity alone will cause the oil to flow; and there should be no sags, bad bends, or contractions in the pipe at any point, as they will cause the oil to be held in the pipe until a sufficient difference of pressure is established between the lubricator and the steam chest to force out the oil.

CARE OF LUBRICATOR

35. Much annoyance and delays and many broken glasses can be avoided if a lubricator is cleaned out at least once a week. The better way to clean out a lubricator is to use the condensation that is in the body and

condenser, when all the oil is fed out. Leave the pressure turned on; close all feeds but one. Open the vent stem to that feed. The water will circulate and wash out any substance that has collected or adhered to the feed-stem or feed-nozzle; at the same time the glasses will be cleansed of particles of gaskets, and dirt and sediment will be blown out. Close the vent stem. The glass immediately fills with condensation from the lubricator. Repeat the same operation for other feeds. Blow off the body, and fill as in usual practice.

Some grades of oil, however, leave a residue that forms a gummy deposit that cannot be removed by blowing out the lubricator; this must be removed by immersing the lubricator in lye. The discoloration of the feed-glasses can be removed or prevented by swabbing the glasses out with glycerine. Strong, soapy water will have the same effect.

There are two reasons why the oil should be strained before filling the lubricator: (1) it prevents, to some extent, the formation of the gummy deposit just mentioned, and (2) it avoids the possibility of small pieces of dirt getting into the reservoir and stopping up some of the passages. The openings through which the oil must pass are, in some lubricators, only $\frac{1}{32}$ to $\frac{3}{64}$ inch in diameter, so that, if the oil is at all dirty, these openings will soon become choked and prevent the feed from operating. It is best not to entirely fill the reservoir with oil, as the expansion due to heat may force some of the oil into the condenser, and, in some styles of lubricator, into the boiler also.

INDEPENDENT AIR-PUMP LUBRICATORS

36. The Nathan Lubricator.—The Nathan independent air-pump lubricator is shown in Fig. 16, (*a*) being a section and (*b*) an elevation. Connection is made at *A* with the air-pump supply pipe, so that, when the steam valve *S* is open, steam passes through *Y* and the condenser tube *34* into the condenser *1*. Steam can also pass through the choke plug *5* into the upper feed-arm, so that the pressure above the water in the glass is equal to the pressure in the

condenser. The condenser remains nearly full of water, which can pass into the reservoir through the water pipe *23*. The oil in the reservoir is thus raised and forced into the oil pipe *22*, as shown by the arrows. When the regulating valve *18* is opened, the head of water in the lubricator forces the oil through the valve; it then floats to the surface of the water in the glass, and is carried through the choke plug *5*

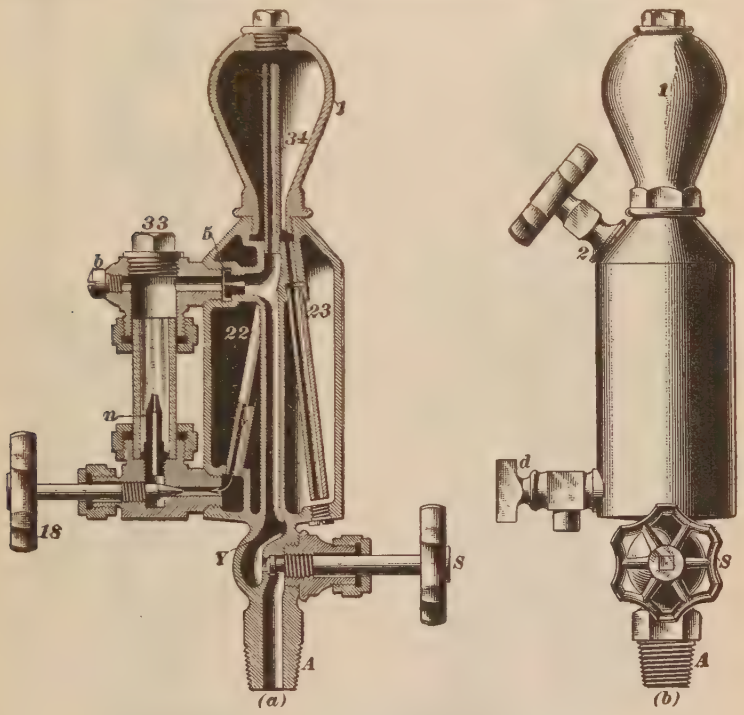


FIG. 16

into the passage *Y*, where it passes to the steam-supply pipe by the force of gravity.

To start this lubricator, open valve *S*, and regulate by means of valve *18*. The lubricator may be stopped by closing valves *18* and *S*.

To refill the reservoir, close valves *18* and *S*, draw off the water from the reservoir through the drain cock *d*, and fill

with clean strained oil, by removing the filling plug *2*. A broken glass may be replaced by removing the plug *33*. About once every 2 weeks the lubricator should be blown

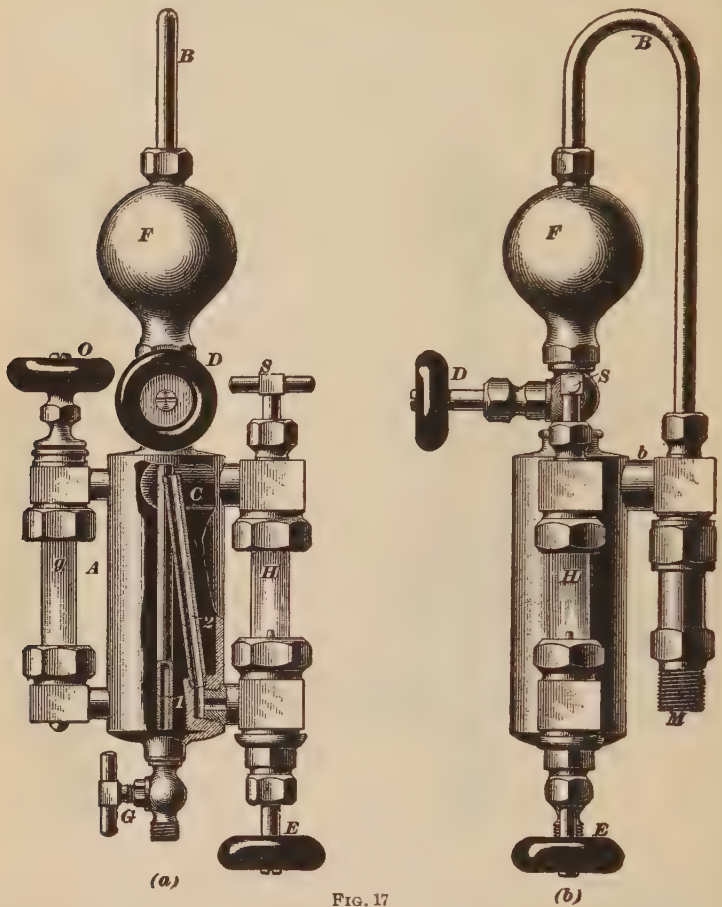


FIG. 17

out with steam. This is accomplished by opening the drain cock *d* and valves *18* and *S*.

To clean out the choke plug *5* when stopped up, remove blow-out plug *b*, close the valve *18*, and open the valve *S*. To clean out the feed-nozzle *n*, remove blow-out plug *b* and open valves *18* and *S*.

Sometimes the condenser *1* becomes charged with air so as to exclude the steam and prevent the formation of condensed water, which stops the operation. To again start the lubricator operating, unscrew the plug in the top of the condenser until steam works out around the joint; the air will then be expelled, after which the joint can be tightened.

37. The Detroit Lubricator.—In Fig. 17 is shown the Detroit No. 1 improved air-pump lubricator, view (*a*) being a part section and (*b*), an elevation. *A* is the oil reservoir, broken away in view (*a*) to show the arrangement of the water tube *1* and the oil tube *2*. *H* is the sight-feed glass; *g*, the oil gauge glass; *D*, the water valve; and *O*, the filling plug. Connection with the air-pump steam-supply pipe is made at *M*, steam passing through the tube *B* into the condenser *F*. Steam also passes through the connection *b* and a passage *C* in the casting to the upper feed-arm, thus maintaining a pressure in the feed-glass *H* equal to the condenser pressure. The condenser fills with water, which, when the water valve *D* is opened, passes to the bottom of the reservoir and forces the oil upwards, and so into and through tube *2* and the regulating valve *E* into the feed-glass, whence it passes through the supporting post *M* to the air-pump steam pipe. *S* is the safety check-valve.

To start the lubricator, open valve *D* and regulate the feed by means of valve *E*; to stop, close *E*.

The reservoir is filled by means of the filling plug *O*. To blow out the cup with steam, close valve *D* and open valve *E* and drain cock *G*.

If air collects in the condenser *F*, as explained with the Nathan lubricator, slack off the union nut until the lubricator is relieved of air, and then tighten the nut.

DETROIT SIGHT-FEED AIR-CYLINDER LUBRICATOR

38. Construction.—The **Detroit sight-feed air-cylinder lubricator** is an auxiliary device that may be used in conjunction with any locomotive lubricator to provide a convenient means of control of the lubrication to the air cylinder of the air pump. It is connected to and receives its supply of oil from the oil reservoir of the locomotive lubricator and, as shown in Fig. 18, consists of the emergency valve 1, sight feed 2, and the check-valve connection 3, together with suitable piping *a* and *b*.

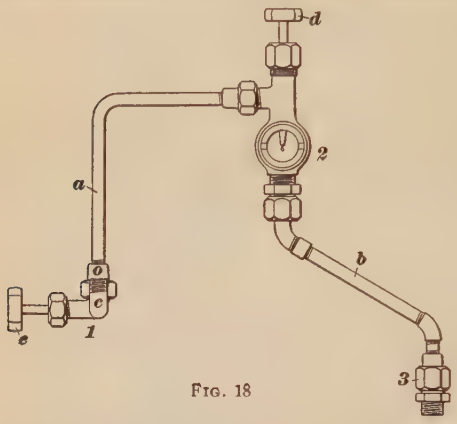


FIG. 18

The emergency valve, Fig. 19, has its branch *c* screwed into the opening made by removing the plug 23, Fig. 11, so that the branch *c* is directly connected into the oil passage *o*. The branch *o* connects to the pipe *a* that leads to the sight-feed 2, Fig. 18. This valve is provided so that the oil supply can be cut off in case the sight-feed has to be changed, or in case there is leakage in the pipe *a*. The emergency valve must not be used to regulate the feed of the oil; this is accomplished by means of the regulating valve *d* of the sight-feed, Fig. 20.

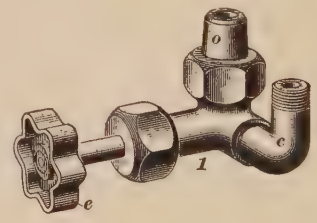


FIG. 19

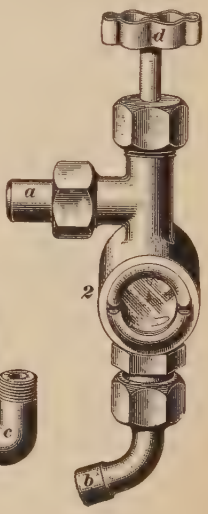


FIG. 20

The sight-feed fitting consists of a regulating valve *d*, similar in construction to the regulating valve 8, Fig. 11; a sight-feed glass,

like the bull's-eye glass of the regular Detroit locomotive lubricator; and two pipe connections *a* and *b*. As there is no water in the sight-feed fitting, the feed is a down-drop feed.

This fitting can be located at any point convenient to the engineer that will not raise it too high for operation. It is connected to the check valve connection by means of the pipe *b*, Fig. 18.

The check-valve connection screws into the tapping in the air-cylinder head that is provided for the oil cup. It consists

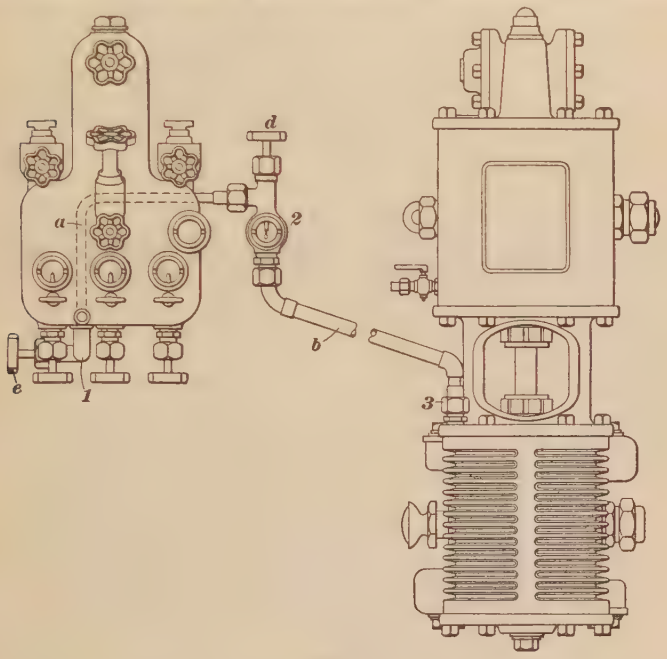


FIG. 21

of a ball check that seats upwards, and its object is to prevent the air from being forced into the oil pipe *b* from the air cylinder.

39. The general arrangement of the parts and the method of piping them to the locomotive lubricator and to the air pump is shown in Fig. 21. When all the oil has fed from the oil reservoir of the locomotive lubricator, the reservoir

stands full of water. To prevent this water from feeding into the air cylinder at such times, the pipe *a* must be brought straight up to the height of the top of the oil reservoir and then carried horizontally to the sight-feed fitting. If it is desired to place the sight-feed at a point lower than the lubricator, the pipe *a* must first extend up to the desired height and then may be brought down to the sight-feed

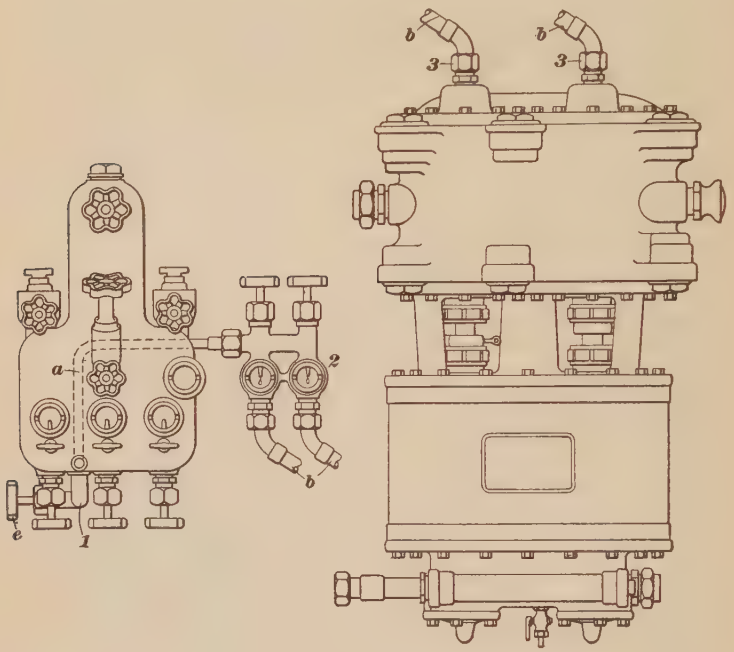


FIG. 22

fitting. The pipe *a* thus forms a trap that will prevent the water from feeding into the air cylinder.

The pipe *b* must slope to the air cylinder without any sags, pockets, or bends that will form a trap, as any pocket or trap will interfere with the proper flow of the oil to the cylinder.

40. Operation.—The operation of this lubricating device is as follows: When the emergency valve 1, Fig. 21, is

open the pressure in the oil reservoir of the locomotive lubricator, owing to the steam pressure and to the head of water in the condenser, forces the oil up through pipe *a* to the regulating valve *d*; this valve being set, the oil passes it in drops and is carried through the delivery pipe *b* to the air cylinder by gravity assisted by the vacuum formed in the upper end of the air cylinder.

The lubricator just described is the single-feed lubricator intended for use with one $9\frac{1}{2}$-inch or one 11-inch Westinghouse air pump. A double-feed lubricator is shown in Fig. 22. This is intended for use when two $9\frac{1}{2}$-inch or two 11-inch pumps are used, or when one New York pump or one cross-compound pump is used. The illustration shows the double-feed lubricator attached to a New York air pump. With the New York pump arrangement, elbow tail-pipes are furnished with the check-valve connection 3.

41. Operating the Device.—The regulating valve *d* of the sight-feed should be set to give drops that occur at proper intervals. Not over 10 drops of oil should be fed at one time. After 10 drops has been fed, the lubricator should be stopped for an interval and then started until not over 10 drops is fed, when it should be again stopped. The intervals between feeds should be as long as the engineer considers best.

BOILER ATTACHMENTS
(PART 3)

SANDERS AND BELL RINGERS

HAND SANDERS

1. General Description.—One of the necessary attachments of an engine is a **sand box.** This is usually placed on top of the boiler so that sand can flow through pipes on each side of the boiler and be delivered to the rails in front of the driving wheels. On switch engines, two sand boxes are sometimes used, one to furnish sand in front of the first pair of drivers, and the other to furnish it behind the back pair of drivers, so that sand can be put on the rails for all the drivers, no matter which way the engine is moving. In a few instances the sand boxes are placed below the running board, in which case one for each rail is needed.

2. Construction and Operation.—A sectional view of a sand box, the valves of which are operated by hand by means of a lever and reach rod, is shown in Fig. 1 (*a*), while a bottom view, showing the mechanism for operating the valves, is shown in (*b*). The sand pipes leading down to the rails in front of the driving wheels connect with the sand box at *x*, while ports *a* lead from the sand chamber *A* to the connections *x*. The openings through ports *a* are controlled by valves *b*; these valves are rigidly connected with the toothed segments *d* by means of the shafts *c*. The toothed segment *e* is rigidly connected to the lever *f*, which is operated by a reach

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rod g, extending back into the cab. By moving the reach rod, the segment e is made to rotate around the point h; this movement causes the segments d to rotate and thus open or

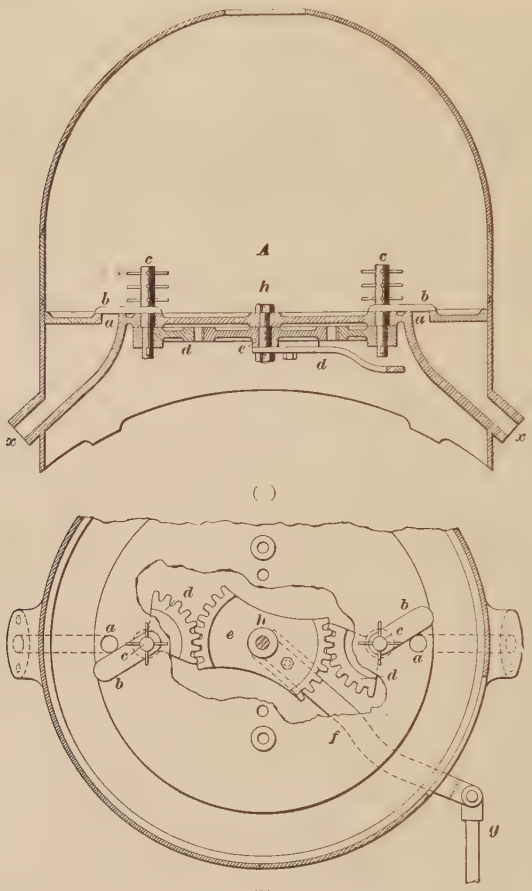

FIG. 1

close the valves b, depending on the direction of the movement. When the valves b are opened, sand flows by gravity from the sand box A through the sand pipes to the rail. This method of sanding the rails is not very satisfactory, for the reason that the sand is delivered with so little force that in

windy weather it is liable to be blown to one side of the rail instead of being delivered to the driving wheels; besides, it is wasteful of sand, and there is practically no means of regulating the amount of sand delivered; hence, air sanders, which have a more positive action, are now in general use.

AIR SANDERS

3. General Description.—Sanders that force the sand to the driving wheels by means of a jet of compressed air are called **air sanders.** There are several types of air sanders in use, but as they all operate on about the same principle, only the **Leach** sander will be described.

In Fig. 2, a Leach sander, known as the *D double sander*, is shown applied to an Atlantic type engine. A pipe connection is made to the sand box at *x*, and a short pipe connects this with the **Y** fitting *a*, which should be located as high up on the boiler as practicable, in order to have as high a column of sand above the trap *D* as possible. Two sand pipes *b*, *c* connect *a* with the double trap *D*; this trap, as its name implies, is composed of two traps in one case, one for discharge pipe *f* and the other for discharge pipe *g*. The air nozzle *e* is connected to the air pipe *j* and discharges sand through the discharge pipe *f*; another air nozzle *h* back of the pipe *f* is connected to the air pipe *i* and discharges sand through the pipe *g*. The air pipes *j*, *i* are connected to the brake-valve main-reservoir connection at *b*, so that the air pipes draw their supply from the main reservoir. The two cab valves *m*, *n* control the flow of air through the pipes; hence, they operate the sander. To force sand through the pipe *g* in front of the drivers, open valve *n*; to force sand through the pipe *f*, open the valve *m*. The discharge pipes should be so bent as to deliver the sand direct to the point of contact of the driving wheel and the rail, as by so doing less sand need be used to be effective.

4. Cab Valve.—The cab valve is illustrated in Fig. 3, in which part of the valve case is broken away and the valve

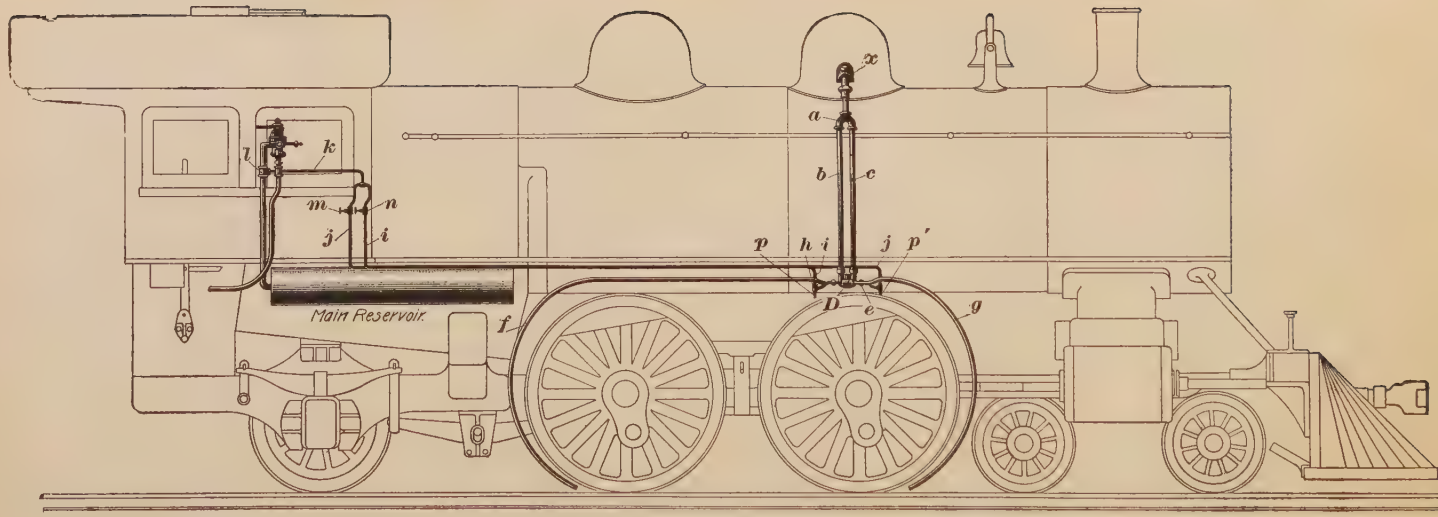

FIG. 2

and valve stem sectioned to show the warning port w. The pipe from the main reservoir connects at x, while the pipe leading to the sander connects at y, so that the air passes from x to y, as indicated by the arrows; also, when the valve is open, there is a discharge of air through the port n, as indicated by the arrows, which makes a noise that warns the engineer that the sander is in operation. Plug O should be held closed while operating the sander.

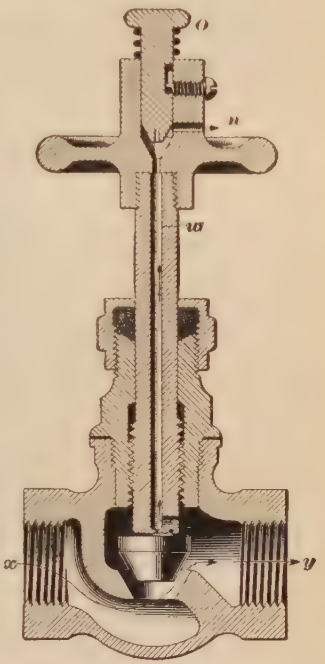

Fig. 3

5. Air Nozzle.—The extension air nozzle used with this sander is illustrated in Fig. 4, in which p is the adjusting tube; r, a check-valve; and j, the air pipe leading to the main reservoir. The port s in the union tail-piece is $\frac{3}{32}$ inch in diameter and forms the air jet. The check-valve r prevents sand passing back into the air port s, stopping it up, while the thumbscrew t permits the port s to be cleaned out should it become stopped up.

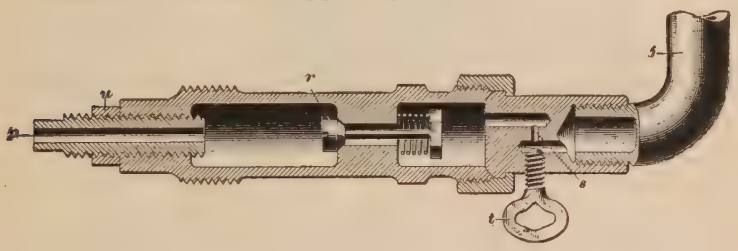

Fig. 4

6. Operation of Sander.—An assembled view of the sanding device is shown in Fig. 5, in which all the parts have the same letters as in the previous figures. In this view,

the pipe *g* and its nozzle are shown in section, whereas the pipe *f* and its nozzle do not show, since they are behind pipe *i*. The sand pipe *c* connects with a chamber *C* in the trap *D*, while the sand pipe *b* connects with a similar chamber; these

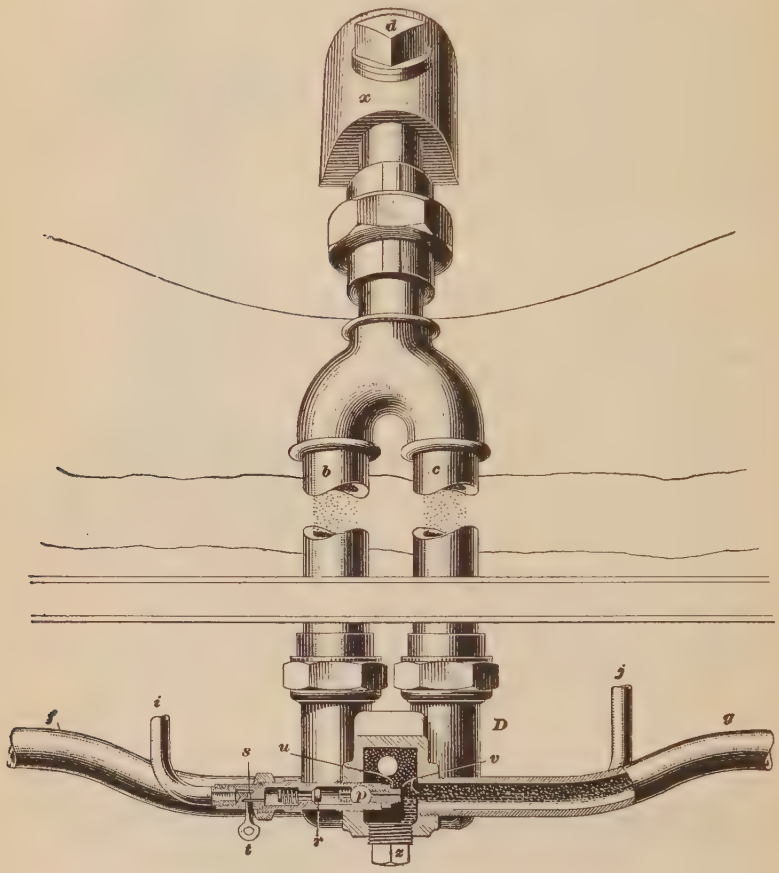

FIG. 5

chambers, however, have no connection with each other, one being used for each discharge pipe. Sand from the sand box flows through the pipes *c*, *b* and keeps the chambers full, some of the sand finding its way into the discharge pipe, as shown. The pipes are bent up at an angle of 15°, to prevent

the sand jarring out of the traps when the engine is running. The resistance of the column of sand in the pipes *b* and *c* is such as will permit considerable air pressure to be used to force any obstruction out of the discharge pipe without permitting the air to escape into the sand box. When it is desired to use sand through the pipe *f*, Fig. 2, air is admitted into the pipe *i*, from whence it passes through port *s*, Fig. 5, the check-valve *r*, and the adjusting tube *p*, into the pipe *f*, forcing the sand through the pipe. As the sand is forced out, more flows in from the chamber *C*, and a continuous stream is thus forced out of the discharge pipe. The amount discharged is regulated by the clearance *v*, increasing or decreasing this by loosening the jamb nut *u* and moving the adjusting tube as required. These nozzles on both sides of the engine should always be adjusted alike, so that they will deliver the same amount of sand.

The inch plug *z* is for the purpose of removing small stones, etc. that may get into the trap and interfere with the operation of the sander. Before this is removed, however, the hand-lever valve in the box must be closed; or, if not provided, the plug *d*, in the sand-box lug, should be removed and a piece of waste inserted to stop the flow of sand to the trap *D* while it is being cleaned.

The operation of the sander for the pipe *g* is the same as that just described.

The pipes *p* and *p'* are the air pipes leading to the opposite side of the engine; they furnish the air necessary for the operation of the sanding devices on the opposite side of the engine.

In most cases, engines are furnished with both hand and air sanders, the former being used in case the air sander becomes inoperative.

7. Care.—Sand intended for use in air sanders should be well screened to remove small stones and any foreign matter that may interfere with the proper operation of the sander; also, the sand should be properly dried before being used, since if damp it will not run freely, and if wet may

plug the pipes and passages. All pipe joints, therefore, must be made water-tight, and the main reservoir must be drained frequently to prevent moisture from that source being carried into the trap and thus affecting the operation of the sander.

This sander is sometimes placed underneath the running board, but the later practice is to place it up close to the sand box so as to be easily accessible, and it should be inspected frequently.

8. Troubles.—Sometimes, when the sand has not been properly screened, small stones accumulate in chamber *C* of the trap *D*, and restrict or entirely prevent the flow of sand into the discharge pipe; or, the sand in the trap may be so wet as not to flow. In either case, if the sand outlet from the sand box can be closed by the valve in the box, do so; if it cannot, remove the plug *d*, Fig. 5, and insert sufficient waste to stop the flow of sand from the box; then remove the plug *z* and clean out the trap.

In the event of the thumbscrew *t* being lost, there will be a bad blow at that opening during the time the cab valve is open, and no sand will be delivered through the discharge pipe, as there will not be sufficient pressure to force it through. This may be remedied by screwing a hardwood plug into the opening, taking care not to screw it in so far that it closes the small air port *s*.

If the air port *s* becomes stopped up, the sander will not work, as no air can come into the nozzle to force the sand out of the discharge pipe; in that event, remove the thumbscrew *t* and clean out port *s*.

If air leaks by the valve in the cab, its moisture will be absorbed by the sand in the trap and stop the sander from working.

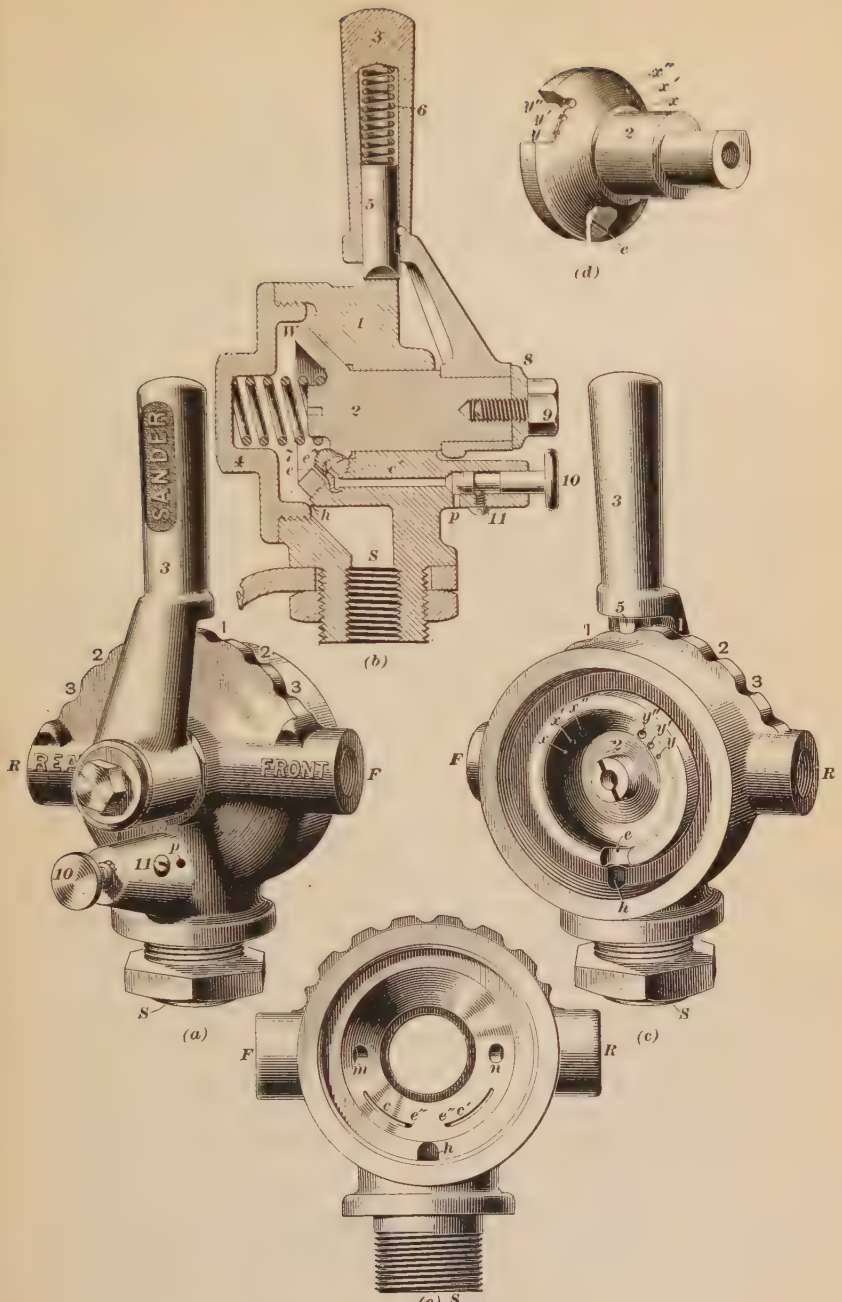

FIG. 6

DUPLEX ENGINEER'S VALVE WITH WARNING ATTACHMENT FOR OPERATING PNEUMATIC SANDERS

9. The **duplex engineer's valve with warning attachment,** shown in Fig. 6, was designed to take the place of the two cab valves *m* and *n*, Fig. 2, and to perform their functions. The valve should be mounted on a bracket in a convenient position and with the side shown in Fig. 6 (*a*) toward the engineer. It is operated by a handle *3*, which can be moved from one end of the quadrant to the other. When the handle is in the middle notch as shown, the sander is not operating. When the handle is in any notch in front of the middle notch, the sander feeds sand in front of the front drivers. With the handle back of the middle notch, the sander feeds sand back of the back drivers.

10. Construction. — View (*a*) is a front view of the valve; (*b*), a vertical sectional view through the center of the valve; (*c*), a back view with the cap *4* and spring *7* removed to show the valve chamber *W* and the face of the valve *2*; (*d*), a back view of the valve *2* with the valve broken away so as to show how the ports pass through it; and (*e*), a back view of the valve body *1*, with the cap *4*, spring *7*, and valve *2* removed to show the ports and grooves in the seat of the valve *2*. The air-supply pipe connects to the valve at *S*, through which air from the main reservoir is supplied to chamber *W* through port *h*, views (*b*) and (*e*). The discharge pipe for the front drivers connects to the valve at *F*, while the discharge pipe for the rear drivers connects at *R*.

Referring to view (*b*), *1* is the valve body that provides a seat for the main valve *2*, and *3* is the handle that contains a spring *6* and latch *5* to hold the handle in the desired position in the quadrant. The handle is secured to the main valve by the washer *8* and capscrew *9*. The main valve *2* controls the flow of air to the front and rear sanders and to the warning valve *10*. Spring *7* prevents the main valve from becoming unseated when there is no pressure in chamber *W*. At *10*

is shown a warning valve that is held in place by the set-screw *11*.

The ports *y*, *y'*, *y''* and *x*, *x'*, *x''* and the warning port *e*, view (*d*), all extend through the main valve *2*, as shown. The passage *e'*, view (*b*), extends from the warning valve *10* through the valve body toward the main valve seat, near which it branches into two ports *e''*, view (*e*), that end in the grooves *c* and *c'* in the valve seat. The grooves *c* and *c'*, therefore, are always connected to the warning valve by way of the ports *e''* and port *e'*. Port *p*, view (*b*), extends from the warning valve to the atmosphere. Port *m* in the valve seat, view (*e*), leads to the connection *F*; port *n* leads to the connection *R*.

11. Operation.—To operate the front sanders, move the handle *3* ahead into one of the notches *1*, *2*, or *3*. When the handle is in notch *1*, port *x* in the valve *2* registers with port *m* in the valve seat, so that air from chamber *W* passes through ports *x* and *m*, the connection *F*, and the air pipe to the front delivery pipe. If a greater supply of sand is desired, the handle is moved to notch *2*, so that port *x'*, which is larger than port *x*, registers with port *m*. When the handle is placed in notch *3*, the largest port *x''* registers with port *m* and the greatest supply of air will be conveyed to the front sanders.

To operate the rear sanders, the handle is moved back from the middle notch. When placed in the first notch, port *y* in the valve registers with port *n* that leads to the connection *R* and the discharge pipe to the rear sanders. To increase the flow of air to the rear sanders, move the handle to the second notch so the larger port *y'* will register with port *n*. When the handle is placed in the third notch, the largest port *y''* registers with port *n*. Whenever the handle is placed in any notch in the quadrant except the center, the warning port *e* in the valve *2*, registers with one of the grooves *c* or *c'* in the seat and allows air from chamber *W* to reach the warning valve *10*. When the handle is in the center notch, port *e* is blanked by the bridge between the two grooves *c* and *c'* and no air can escape through the

warning port. The escape of air at the warning valve warns the engineer that the sander is in operation. This escape of air may be temporarily stopped by holding the valve *10* in by the hand, but the blow will be resumed as soon as the hand is removed and will continue as long as the sander is in operation.

LOCOMOTIVE BELL RINGERS

DUTIES OF BELL RINGERS

12. The duties of a locomotive fireman, especially on heavy trains in and around cities, are such that it is practically impossible for him to give proper attention to his fire and at the same time ring the bell when and where he should. On the other hand, the engineer's attention is so taken up with his duties that he cannot, with safety, attend to ringing the bell, hence the necessity of automatic *bell ringers*.

A **bell ringer** is an apparatus attached to the bell in such a way as to ring the bell when in operation. Bell ringers are usually operated by air pressure, although steam is sometimes used for that purpose. Once started, they are wholly automatic in action. They not only relieve the enginemen of the duty of ringing the engine bell, but make certain that the bell is rung continuously, when necessary.

GOLMAR PNEUMATIC BELL RINGER

13. General Description.—Two views of the **Golmar bell ringer** are given in Fig. 7, in which view (*a*) shows the parts in the positions they occupy at the beginning of the up stroke of piston *2*, and view (*b*) shows them at the beginning of the down stroke. In the illustration, *1* is the valve body; *2*, the piston; *3*, the crank-rod that works in the sleeve *3'*; *4*, the crank; *5*, the valve; *6*, the valve stem; and *7*, the governor bolt. The air-supply pipe connects to the valve body at X; the exhaust port Y leads into chamber A, and is connected by the passage z with chamber E, thus

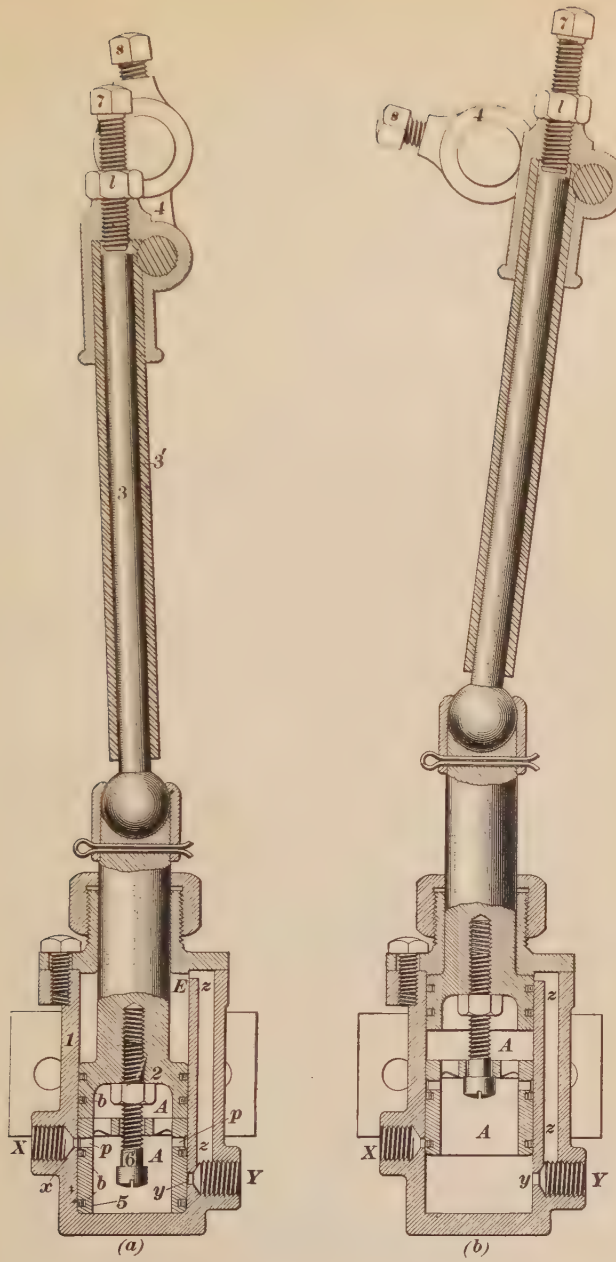

FIG. 7

allowing any leakage past piston *2* to escape to the atmosphere. The piston *2* is provided with packing rings *b* to prevent leakage past it. The crank-rod *3* has a ball-and-socket joint at one end, and works within the sleeve *3'*. The bell-crank *4* is connected to the bell shaft by the setscrew *s*, and to the crank-rod sleeve *3'*.

The valve *5* is provided with packing rings *b*, and has a groove around the outside that connects with the inside of the valve by the port *p*. It is open both top and bottom, so that chamber *A* extends from the bottom of the valve body *1* into the cavity of the piston *2*. The valve is operated by the piston *2* through the medium of the valve stem *6*, which is screwed into the piston. After the piston moves up sufficiently for the head on the stem *6* to engage the valve, the valve is moved up with it; as the piston moves downwards, it pushes the valve to its bottom position.

14. Operation. –The piston *2* always comes to rest at the lower end of its stroke, as shown in view (*a*). When air is turned into the ringer, it enters chamber *A* through ports *x* and *p*, and forces piston *2* upwards. When the head of the valve stem *6* comes in contact with the valve *5*, it raises the valve and closes port *x*. The air in chamber *A*, however, continues to expand and raises piston *2* and the valve *5* until the valve opens the exhaust port *y*. As soon as chamber *A* is relieved of pressure the weight of the bell forces piston *2* downwards; this opens port *x* again and admits air into chamber *A*, causing another up stroke of the piston, and so on for succeeding strokes. When the valve *5* closes port *y* on its down stroke, it compresses the air remaining in chamber *A*, thus forming a cushion for the piston *2*.

15. Regulation.—The force with which the piston *2* makes its up stroke depends on the amount of air admitted into chamber *A* before port *x* is closed. This is regulated by the stem *6*, which is adjustable. Screwing up stem *6* causes the valve *5* to be raised and closes port *x* earlier in the stroke, thus decreasing the quantity of air admitted into chamber *A*. Unscrewing stem *6* increases the supply into the

chamber before port *x* is closed. Once properly adjusted, the valve stem *6* should not be disturbed with a view of changing the throw of the bell; this is accomplished by means of the governor bolt *7*.

16. *To regulate the throw of the bell*, the governor bolt *7* should be adjusted properly. To increase the throw, loosen locknut *l* and screw bolt *7* toward the crank-rod *3* the proper amount; then tighten locknut *l*. If bolt *7* is screwed too far, the bell will turn over. To decrease the throw, loosen nut *l*, and screw bolt *7* away from the crank-rod the proper amount; then tighten nut *l*.

17. Leaky Supply Valve.—A leaky supply valve to the ringer will act as follows: The air leaking into chamber *A* gradually forces the piston upwards until the valve *5* is moved far enough to almost blank port *x* but not far enough to open the exhaust port *y*, when it will be held stationary with the bell tilted in the air. Port *x* will be open just far enough to supply the leakage from chamber *A*. Once the bell is tilted, it will be impossible to start it ringing until the rod *6* has been raised sufficiently to open the exhaust port *y*. This can usually be accomplished by swinging the bell by means of the bell rope. The rod *6* is thus raised from the piston *2*, relieving it of the weight of the bell, and the air pressure in chamber *A* is then sufficient to raise the rod the proper amount to start the ringer operating. This trouble will occur each time that the bell stops ringing until the leaky supply valve is repaired.

BOILER FEEDING AND MANAGEMENT

WATER CIRCULATION

18. Radiation, Conduction, and Convection.—Heat is transferred from one point to another in three ways: by *radiation*, by *conduction*, and by *convection*.

When one body appears to impart heat directly to another at a distance, the heat is said to be transferred by **radiation.**

When heat is transmitted from points of high temperature to points of low temperature, by passing from one particle of a body to the next particle, and so on, it is said to be transmitted by **conduction.** This is the mode by which heat is transmitted through solid bodies, the metals being the best heat conductors.

If a portion of a liquid is heated above the temperature of the surrounding portions, it expands and is thus made lighter. This causes it to rise up, while the cooler and, consequently, heavier portions rush in from all sides to take its place. As the heated liquid rises, it comes in contact with cooler liquid, with which it shares its heat, and in this way all the liquid becomes heated. This mode of transmitting heat by the motion of heated fluids is called **convection,** and the currents thereby induced are called *convection currents*.

19. Illustration of Terms.—An idea of the difference in the modes of conveying heat by conduction and by convection may be obtained by the following illustration: Suppose that a pile of sand is to be conveyed to a point, say, 100 feet away, and that a number of men are stationed at short intervals between the sand and the point of delivery. If the first man fills a pail with the sand and passes it along the line to the point of delivery, the mode of conveyance will illustrate *conduction*. If, on the other hand, each man has a

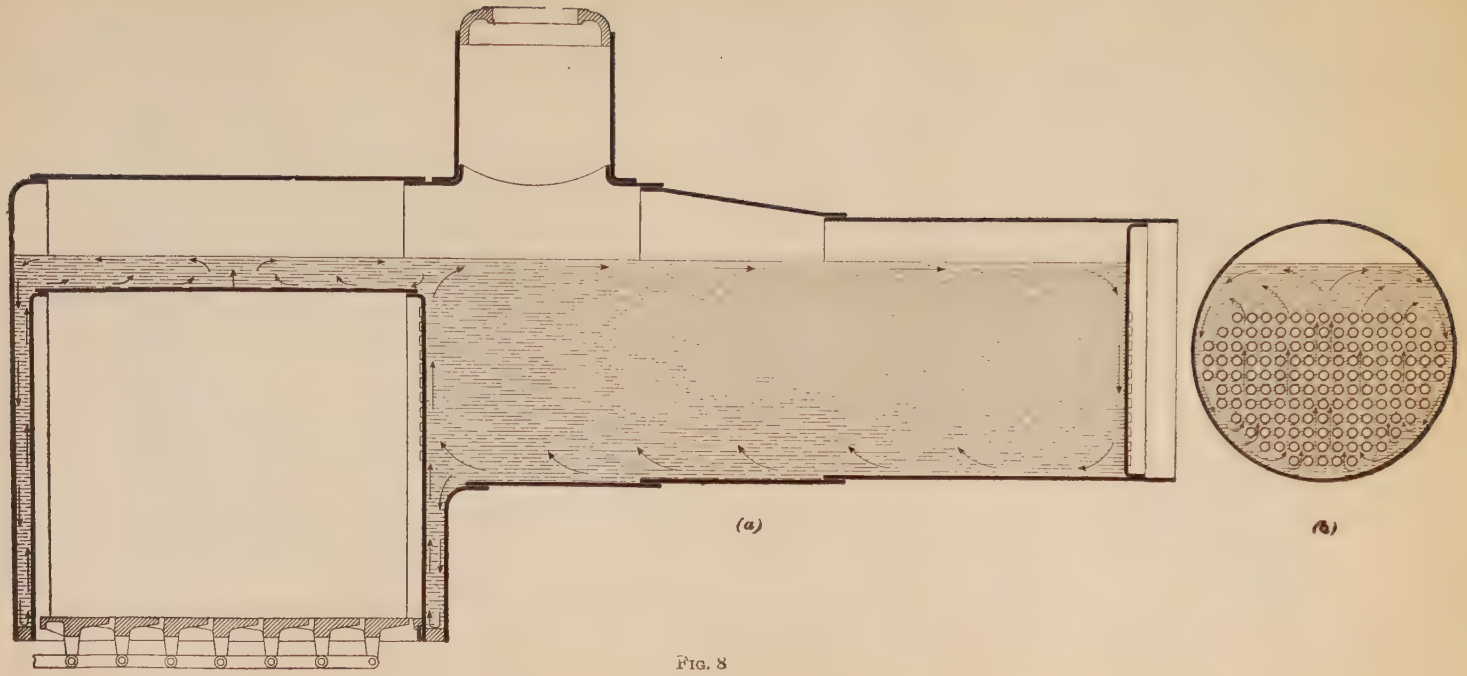

FIG. 8

pail that he fills at the sand pile and then carries to the point of delivery, the mode of conveyance will illustrate *convection*, and the stream of men passing back and forth will represent the convection currents. With the exception of the liquid metal, mercury, the heat-conducting power of liquids and gases is very low, and heat is transmitted through them chiefly by convection.

It is due to this principle of convection that the water in a boiler is caused to circulate, and the rapidity with which heat will be absorbed from the heating surfaces depends on the effectiveness of the circulation in the boiler.

20. Circulation in Boiler.—Proper circulation of the water is essential to the efficient operation of a boiler, as it tends to keep all parts at a uniform temperature, and therefore is a safeguard against overheating or cooling below the temperature of the other parts of the boiler. Besides this, when the circulation is good, it prevents to some extent the deposit of lime that accumulates from the feedwater. The circulation of water in a boiler is illustrated in Fig. 8, where (*a*) is a longitudinal section and (*b*) is a cross-section. The motion of the currents is shown by the arrows. The heated currents rise and carry the bubbles of steam to the surface, the cooler water rushing in to take their places over the heating surface, and thus the circulation is maintained. View (*a*) shows the hot water rising up and flowing toward the front end, while the cooler water sinks and flows toward the rear end. In view (*b*), the warm water is seen flowing up between the tubes, and the cold water flowing down in the space between the tubes and the shell of the boiler. Since the cooler water flows toward the rear end, the circulation is aided by introducing the feedwater as far ahead as possible. The coolest water circulates around the front end of the tubes in which the gases are about to pass out into the smoke arch, and thus the greatest amount of heat is absorbed from the gases by the water. This, however, is not the chief reason why the boiler checks are placed so far ahead in locomotive boilers; when the water

is introduced near the front end, it is heated considerably before it comes in contact with the hot firebox sheets, which, therefore, are not subjected to such sudden contraction as would otherwise be the case, and hence are less liable to leak or crack. When an injector is supplying water to a boiler having a full pressure of steam, the temperature of the water supplied is usually about 200° below that of the water in the upper part of the boiler. As the cooler water always settles to the bottom of the boiler and then rises as it gets hotter, unless there is a good hot fire in the firebox, in a short time the lower part of the boiler will be filled with the cooler water, which cools off the lower tubes and firebox sheets much below the temperature of the upper rows of tubes. This makes the lower ones contract, and they will surely leak.

If there is a good fire, it will keep the water circulating through the tubes, as shown in Fig. 8 (*b*), before it gets back to the firebox sheets, and thus no part of the boiler will cool off and contract before the other. For that reason, when feeding a boiler a good fire is necessary to cause the water to circulate properly and not cool off one part more than another.

FEEDING THE BOILER

21. General Remarks.—On account of the inability of most boilers to make sufficient steam to handle a heavy train on short pulls or when taking a run for a short grade, it is not altogether advisable to attempt to maintain a **constant height** of water in the boiler when dealing with *short* grades, for the following reasons: If such is done, the injectors will have to be worked so as to supply water at just the same rate at which it is being used. In other words, when the engine is doing the least work, the least amount of water will be injected into the boiler, while at times when it is working at its full capacity, the greatest quantity of water will be injected.

Now, as it requires from 20 to 30 horsepower to operate the injector at about its maximum capacity, and as this

steam must be supplied by the boiler, it is evident that operating the injector to its full capacity has the effect of considerably reducing the capacity of the boiler. So long as the engine is working light, this reduction of boiler capacity makes no difference, but, at such times as the engine has to exert its maximum pull, the reduction referred to becomes a serious matter.

Working the injector at full capacity at such times has the following effect: When water is fed into the boiler while steam is being used, the fire has to supply the heat necessary to raise this water to the steaming point under boiler pressure, in addition to supplying the heat that the engine converts into work. Now, if the water is injected into the boiler at the same rate that it is being used, then, the harder the engine is working, the more heat must be used in heating the water injected, so that there will, consequently, be a smaller amount of heat for conversion into work in the cylinders. This has the same effect as though the capacity of the boiler were still further reduced. If there is a good strong fire maintained to heat the water supplied up to the same temperature as the rest of the water in the boiler it is more expedient and economical to feed the boiler when the engine is not working hardest, but when it is working well within its capacity, and advantage should be taken of all such occasions to increase the water supply. These remarks as to maintaining a constant height of water do not apply to cases where, owing to the hill being of great length, or for other reasons, the engine has to work its hardest for prolonged periods. In such cases, the rate of feed must be maintained equal to that at which the engine is using the water.

No hard and fast rule can of course be given for feeding a locomotive boiler, since steam must be supplied to handle the train and so much depends on the nature of the track, the train load, and other conditions, which are seldom the same in any two cases; yet if the principles of boiler feeding and circulation are thoroughly understood, the exercise of good judgment will generally result in the right thing being done in any given case.

22. Economical Feeding. —A good plan, when practicable, is to raise the water level during intervals when the engine is working well within its capacity, and to throttle the water supply or shut off the injector, if possible, during such times as the engine is called on for an extra effort, such as starting a train from a station, relying for the time being on the supply in the boiler. In such a case, having a sufficient supply of water heated to the temperature at which it is ready to turn into steam and stored in the boiler to last while the engine is working hard, the injector may be shut off. It will be much easier, therefore, to maintain steam pressure during the heavy pull, and, by forcing the fire, steam can be generated at a much greater rate. In this way, the boiler can be worked to its utmost steaming capacity, which will enable the locomotive to deal with loads that with a poor steamer would stall it.

Economy in coal can also be taken into account in the matter of boiler feeding. It is more economical to maintain a moderate fire at all times than to force the fire to a great extent in order to work the injector at the same rate that the engine is using steam, and shut it off when the steam is shut off. If the injector is worked as moderately as possible consistent with a proper supply of water, and shut off for a short time when pulling out from a station, the fire will not have to be forced to its utmost at one time and choked down to prevent blowing off steam when the engine is not worked; this will aid in coal economy. The feeding, when possible, should be done while the engine is using steam, as the circulation is best at such times and there is less liability of starting the tubes to leak.

23. Ascending a Grade. —In most cases, however, it will be necessary to supply water continuously to the boiler while the engine is working hard, as, for instance, while ascending a long grade. The best plan under such circumstances is to have the boiler as full as practicable when beginning the ascent; then adjust the feed so that, when the engine pitches over the summit, there will be a sufficient height of water left to protect the crown sheet.

24. Before leaving the engine at a terminal, the enginemen should see that there is a full boiler of water and a good bright fire. Feeding the boiler at the clinker pit or when cleaning the fire should be very closely looked after, as putting water into the boiler when there is a low fire or no fire at all on the grates is sure to cause contraction of the lower rows of tubes and make them leak. For this reason the boiler should be filled before arriving at the cleaning pit and while there is a bright fire on the grate to heat the water as fast as it is supplied. It is not unusual to see both injectors put on while the fire is being knocked out, with the usual result—leaky tubes.

25. Height of Water.—It is better to carry a moderately **high,** rather than a **low,** water level, for the following reasons: (1) With a good supply of water in the boiler, the feedwater will have less cooling effect, and both the temperature of the water and the steam pressure will remain more nearly uniform. (2) If the injectors should fail, the larger volume of water will allow more time for examination and repair of the injectors before it becomes necessary to draw the fire. (3) It enables the engineer to shut off the injector for a short interval, and thus favor the fireman when necessary. In fact, the feeding and firing should be worked in harmony; the fireman must keep a good bright fire whenever the injector is working, and the engineer should feed the boiler in such a way as to assist the fireman as much as possible.

FOAMING AND PRIMING

FOAMING

26. When certain impurities are present in the boiler, they cause the water to **foam** and suds to form on its surface. **Foaming** may be due to the presence of impurities, such as alkali or soda in excess, grease, soap, some kinds of oil, and

such other substances as will cause the formation of suds. It is generally indicated by the rapid rising and falling of the water in the glass. Sometimes the water has a "riled" appearance, and, generally, it discharges from the stack. The valves become dry, and jerk and rattle the reverse lever, and in some instances the valves or pistons groan and squeak, showing that all the oil has been washed away and that the parts are dry and cutting. In such cases, the amount of lubrication should be increased.

Foaming affects the reading of the water gauges, and makes them indicate too high a level; there is danger, therefore, of the crown sheet being overheated, and for that reason the true water level should be ascertained the instant that indications of foaming appear.

The best method is to open the drain cock on the water gauge and empty the glass; then close the cock and note the height to which the water rises before it begins to foam. This is the true height of the water. The water level should thus be ascertained very frequently when the water is foaming, so as to prevent the crown sheet from being burned. Another method is to ease off the throttle gradually. If the water level is high and it remains at practically the same height as when the throttle is closed, it indicates that the water level is too high rather than that the boiler is foaming; if the water level shows a decided drop as the throttle is closed, the boiler is most likely foaming.

In the event of foaming, open the cylinder cocks, to protect the cylinder heads; place the reverse lever in full gear, and keep the throttle partly open, so as to keep the train moving; then put on both injectors, open the blow-off cocks, and try to blow off the bad water if the height of the water will permit. Ease the throttle off frequently, to see whether the water is being worked off faster than the injectors are supplying it, as such a contingency would endanger the crown sheet. The blow-off cocks should be used frequently, holding them open about 10 seconds, and not over 30 seconds under any circumstances. In using a blow-off cock, there is always danger of its being held open by a piece of scale or

mud. In this emergency, put on both injectors, so as to hold the water level, if possible, until the fire has been drawn.

With bad water there is a great tendency for water glasses and gauges to choke up; consequently, the cocks should be used frequently, and when they show indications of choking up they should be bored out. On some roads the upper water-glass cock is so constructed that it has to be taken out and cleaned with acid.

PRIMING

27. Causes.—When fine particles of water are carried by the steam from the boiler into the cylinders, the boiler is said to **prime.**

Priming may be caused: (1) by insufficient steam space, due either to the design of the boiler or to the water being carried too high; (2) by a sudden release of the pressure, due to the throttle being opened quickly or the safety valves blowing off; or (3) by poor circulation of the water. The water next to the heating surface is always the hottest; therefore, steam is first generated near the heating surface. This steam forms little bubbles, which are prevented from expanding as they rise by the resistance offered by the water. As the bubbles approach the surface, the water exerts less and less resistance to the expansion of these steam bubbles, until, finally, the resistance becomes less than the expansive force, and the bubbles explode and throw small particles of water into the steam space. Now, when the throttle is open, the steam rushing into the dome tends to carry this water spray with it, just as the wind tends to pick up and carry dust off the ground. The more spray thrown up from the body of the water, or the greater the flow of the steam to the dome, the greater will be the tendency to prime. If the water level is high, the steam will have a shorter distance to raise the spray, and the flow of steam will be confined to a smaller space; consequently, the priming will increase.

If the throttle is opened quickly, it reduces the pressure considerably on the water just under the dome. This

causes a greater flow of steam bubbles from all parts of the heating surface to the point under the dome; consequently, the spray at that point is greatly increased, which induces priming.

28. Indications of Priming. The fact that a boiler is priming is indicated by the peculiar flat sound of the exhaust, by water discharging from the stack, and by the color of the steam as it discharges from the top gauge-cock.

Steam is a colorless, invisible gas. The white vapor seen coming from the exhaust is not steam, but fine water particles formed by steam condensing. Steam occupies the space above the water in the glass water gauge, although, since it is invisible, the space seems to be empty. If dry steam issues from a gauge-cock, it cannot be seen for at least an inch from the cock, after which it becomes gradually whiter and whiter the farther it is from the cock. Wet steam appears as a dense white cloud from the moment it issues from the cock, and its color is about uniform throughout, due to the water particles it contains.

As soon as priming is noticed, the cylinder cocks should be opened, to protect the cylinder heads. The cause should then be ascertained and remedied. To distinguish priming from foaming, remember that when the water is foaming the water level will drop considerably when the throttle is shut. If the water is priming, the level will not drop much when the throttle is shut. Foaming is the result of foreign substances in the water; priming is the result of having the boiler too full of water.

29. Effects of Priming.—Priming produces a number of bad effects: (1) It washes the oil from the valves and cylinders, thereby causing the reverse lever to work hard, and the valves and cylinders to cut; also, power is lost, as it requires additional force to overcome the greater frictional resistance. (2) It endangers the cylinder heads, as water is incompressible. (3) Wet steam has less expansive power than dry steam, and does not flow so freely. This causes a reduction of initial pressure, and increases the back pressure,

both of which cause a waste of power. (4) The hot water carried away with the steam does no useful work, the heat it contains being wasted; also, being cooler, it condenses steam with which it comes in contact.

Priming, therefore, is wasteful and should be prevented if possible, as it affects the coal and oil records very materially. It is not a good plan to let the engine slip while water is being worked through the cylinders, as it is liable to cause damage to the engine.

LOW WATER

30. If, through carelessness or otherwise, the water level is allowed to get dangerously low, there is serious trouble. It is very rare that this event is due wholly to carelessness, as no man courts the disgrace of having "scorched" his engine. The trouble is generally with the feeding apparatus. If the injectors fail to work, close the dampers and bank the fire with fine green coal. It is better to deaden the fire in this way than to knock it out, if the water is very low, as the temporary increase in temperature occasioned by drawing the fire may aggravate the trouble. After the fire has cooled down considerably, it may be knocked out if necessary. In that event, if the weather is cold, the boiler must be drained of all water, to prevent damage by freezing. Empty the tank and leave both tank hose uncoupled; drain all pipes, the air pump and reservoirs, as well as the lubricator; and open the cylinder cocks. Then prepare to be towed in. Of course, the train should be fully protected from the beginning.

OIL IN BOILER

31. Effects of Oil in Boiler.—The effect of oil in a boiler depends entirely on its nature. Some oils, as kerosene, have a good effect, as they tend to soften and remove scale; while others, such as valve oil, lard oil, rape-seed oil, grease, and, in fact, all animal and vegetable oils, are very injurious,

as they not only cause foaming, but may also give rise to overheating of the tubes or crown sheet. The solid portion of the impurities in the water is precipitated when the water boils, uniting with the organic matter of the oil (if animal or vegetable), and producing a thick paste-like formation that sticks to the tubes and sheets wherever it comes in contact with them. This deposit is a poor conductor of heat, and, when adhering to the heating surface, will neither pass the heat on to the water nor permit the water to come in contact with the heating surface to absorb it; the result is that the parts coated by this deposit are overheated.

32. Mineral Oil in Boilers.—Mineral oils do not possess the disadvantage of animal oils, and, when properly used, have a good effect both in preventing and also in removing many kinds of scale. Some grades of black oil have been used for this purpose with fairly good results, but, if used in very large quantities, the oil may cause overheating. Kerosene oil has been used with very good results on some roads, and it has not only proved a prevention, but has also been effective in breaking up and loosening hard scale after it has formed. To derive the full benefit from the use of oil for the present purpose, it should be introduced drop by drop with the feedwater. The oil thus fed is carried to all parts of the boiler, and the danger of overheating from its use is reduced to a minimum. It is claimed by those who have used kerosene in stationary boilers that 1 quart a day per 100 horsepower will keep boilers free from most scale formations. Also, a product called "Ruby Oil" is sometimes used for this purpose. It is introduced directly into the boiler by a special lubricator usually attached to the boiler head. This is known as the *Talmage system.*

If, by any means, animal or vegetable oil gets into the tank, the heaters should be used to assist in raising the oil off the surfaces inside the tank, and, at the first opportunity, the tank should be flooded for a considerable time, to pass it off.

SCALE AND MUD

33. Incrustation, or **scale,** as it is usually called, is the deposit formed in a boiler by the precipitation of mineral substances that have been dissolved by the feedwater, or by the settling of mud or earthy matter that has simply been held in suspension in it. These substances accumulate and bake into a hard scale, which may cover the heating surface with a layer $\frac{1}{4}$ to $\frac{1}{2}$ inch in thickness. A thin coat of scale may be of advantage if the feedwater tends to corrode the plates, as it protects the latter to some extent, but a thick coat is both wasteful and dangerous. The scale acts as a non-conducting coat to the heating surfaces; consequently, it not only wastes heat, but also tends to cause the surfaces to overheat.

The carbonates and sulphates of lime, and also carbonate of magnesia, are the most troublesome of scale-forming substances. Carbonate of lime, such as marble and other forms of limestone, dissolves in water that contains carbonic acid. When the water is heated, the carbonic acid is driven off, and the carbonate is precipitated in the solid form. Carbonate of magnesia acts in a similar manner. Sulphate of lime is completely insoluble in water at a temperature of 300° F., so that, if the feedwater is heated to about that temperature, the greater part of the scale-forming materials will be precipitated in the solid form. Carbonate of lime becomes insoluble and is precipitated in solid form when the water is heated to 212° F. Scale formed from sulphate of lime is not deposited until after the water has been heated to 300° F., or more, whereas scale formed from carbonate of lime is deposited at the much lower temperature of 212° F. Scale formed from carbonate of lime is soft and granular, while that formed from the sulphate is hard and crust-like. Organic substances in combination with carbonate of lime make a hard and troublesome scale. Mud settling in the legs of the firebox will prevent the water getting to the firebox sheets; this not only impairs the steaming powers of the boiler, but the sheets become overheated and in a short time are bulged and cracked, the metal having its strength destroyed.

PREVENTION OF SCALE

34. The Railway Master Mechanics' Association has estimated that the losses due to scale, such as loss of fuel, extra repairs, etc., amount to about $750 a year for every locomotive in the Middle and Western States. It is evident, therefore, that the formation of scale and the means of prevention are matters of considerable importance.

The formation of scale may be prevented: (1) by separating the scale-forming substances from the feedwater before it is fed into the boiler; or (2) by removing the soft scale from the boiler before it bakes into a solid crust. The second method is the only one that will be considered.

When the scale is formed from sediment, mud, clay, or readily soluble salts in feedwater, a frequent use of both surface and bottom blow-off cocks will keep the boiler comparatively free from scale. When formed from the carbonates of lime, magnesia, or iron, it is advisable to use caustic soda, lime, or magnesia to prevent the formation of hard scale. When the scale is formed from sulphate of lime, carbonate of soda should be introduced into the boiler. In this case, the sulphate and soda combine and form a sulphate of soda that is soluble, and a carbonate of lime that forms a soft scale that can easily be blown out. Carbonate of soda (soda ash is an impure form of carbonate of soda) should not be introduced in large quantities at a time, however, as it may cause foaming. The proper amount is just .78 times the number of grains of sulphate of lime in a gallon of water. Some organic substances that contain tannic acid, such as the bark from oak or hemlock, and sumac, logwood, etc., have been used in some instances and found effective in loosening or preventing scale formed from carbonates of lime or magnesia; but tannic acid is liable to cause corrosion and had better not be used. Kerosene oil is useful in preventing and removing scale.

CORROSION

35. Forms of Corrosion. Corrosion, or the eating away, of the boiler plates is due to the chemical action of impure water. It is very destructive in its action, and shortens the life of a boiler considerably. Corrosion presents itself in three forms:

1. *Uniform corrosion*, in which large areas of plate waste away, there being no sharp line of division between the corroded part and the sound plate. In some such cases, it is necessary to drill a hole through the suspected plate and measure its thickness.

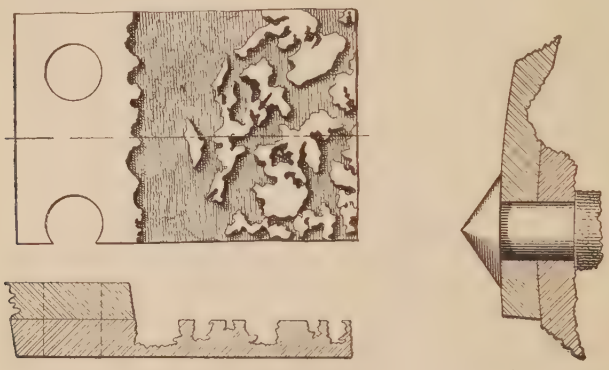

FIG. 9

2. *Pitting*, or *honeycombing*, which can be readily detected, as the plates are eaten away in spots, and are indented with holes and cavities from $\frac{1}{32}$ to $\frac{1}{4}$ inch deep. The appearance of a pitted plate is shown in Fig. 9 (*a*).

3. *Grooving*, which is generally caused by the plates buckling at the joints when under pressure; this starts a small crack that is acted on by the corrosive agents in the water, and soon deepens into a groove along the seam, as shown in Fig. 9 (*b*). Grooving is sometimes the result of careless workmanship in calking, the sharp calking tool leaving a mark all along the seam, which acts as a small crack to start the grooving.

36. Causes of Corrosion. The following are some of the impurities that will cause corrosion in a boiler: (1) Acids; (2) chloride and sulphate of magnesium; (3) grease (giving rise to acids); (4) dissolved carbonic acid and oxygen. To prevent corrosion, therefore, the water must be purified of its corrosive impurities before it is fed into the boiler; or, if the impure water must be used, some agent that will neutralize the impurities should be introduced into the water.

When acids are present in the water, they may be neutralized by adding an alkali; for chloride and sulphate of magnesia, add carbonate of soda. The action of grease may be neutralized by carbonate of soda or slaked lime. Dissolved carbonic acid and oxygen require the addition of slaked lime or caustic soda. When the boiler is known to contain corrosive impurities, its interior should be inspected frequently for indications of corrosion.

BLOWING OFF

37. The way in which a boiler is emptied by **blowing off** is often responsible for the formation of a great deal of scale, and sometimes for cracked sheets and broken stay-bolts where a brick arch is used. A boiler should not be emptied by blowing off under a high steam pressure, except in emergencies. It should be allowed to cool gradually until under a very low pressure, and then emptied. When the boiler must be cooled and emptied quickly, for washing out or for any other purpose, all but about a gauge of water should be blown off, and the boiler then filled gradually with water. The blow-off cock may then be opened, keeping sufficient water flowing into the boiler to keep the water level about constant. By this means, the body of water in the boiler, and, consequently, the boiler itself, will be cooled gradually, the sediment will not be baked on the heating surfaces, and there will be less tendency for sheets and stays to crack and break. When the pressure is reduced sufficiently, the boiler may be emptied, and it should be allowed to cool before again being filled with cold water.

When carbonate of soda or soda ash is used to prevent the formation of scale, frequent blowing out of the water is resorted to, in order to remove the dissolved scale and neutralized soda ash. This should be done often enough to prevent foaming.

When water is blown off to reduce the proportion of bad water in such a case, the blow-off cock should be open about 10 seconds, but not over 30 seconds under any circumstances. Keeping it open longer than that will only waste heat and will not remove any more of the mud.

EXCESSIVE PRESSURE

38. Fortunately, **excessive overpressure** in locomotive boilers is not of frequent occurrence, yet every engineman should understand how to safely relieve the boiler of overpressure, as ignorance on this subject may lead to a disastrous explosion. If the pressure rises above the safe limit, it should be reduced by starting the injectors, closing the dampers, and covering the fire with enough fresh coal to deaden it. Do not open the safety valve, however. The sudden, heavy reduction of pressure caused by quickly opening the throttle or the safety valve produces a violent rush of steam and water against the parts of the boiler adjacent to the valve, and the force of the shock may be sufficient to cause the boiler to give way. Steam valves should never be opened or closed very suddenly at any time; this should be done *very gradually* in times of overpressure.

COLLAPSED TUBES

39. Iron tube plugs, for plugging the ends of collapsed tubes, together with a plugging bar, are generally carried on the engine. In the event of a tube collapsing, it will in all probability deaden the fire sufficiently for protection, when a plug can be put in the tube on the firebox end. To do this, a plug is attached to the end of the plugging bar,

with which it is inserted and driven into the end of the tube. In some cases, the tube may be in such a position that it cannot be plugged by means of the plugging bar, in which case it will be necessary to knock out or bank the fire, to cool off the firebox, before the tube can be plugged.

If iron plugs are not at hand, wooden ones may be made and used; the wooden plug will burn off even with the tube, but no farther. Of course, the train must be protected with flags the moment it is brought to a standstill. While driving the plug in the tube, keep out of its range, so that if it should be forced out by the steam pressure no harm will be done.

If the engine is not provided with a plugging bar, the plug may be fastened to a long pole (if available) and then inserted in the tube end, driving it home with an iron bar or a piece of rail, taking care not to hammer so hard as to injure the sheet. The engineer's first efforts, when a tube bursts, should be to reduce the pressure and to keep up the water level, so as to be able to set about the above operations more quickly.

On many roads the engine crew is prohibited from trying to plug tubes on account of the danger of being scalded.

BOILER INSPECTION

40. Locomotive boilers should be tested and carefully inspected at regular intervals for corrosion, grooving, etc. When a boiler is new or has been repaired, a strength test is applied. This test may be made by the hydrostatic, or cold-water, test; by the warm-water test; or by steam pressure. Sometimes the first two tests and sometimes the first and third are used.

The cold-water test consists in forcing cold water into the boiler by means of a force pump until the required testing pressure is obtained This method will show up leaks that would not be found if the plates were heated, as the expansion of the plates, due to this heat, would stop the leaks.

The warm-water test consists in filling the boiler entirely full of cold water, and then heating the water until, in trying

to expand, it exerts the required pressure. It may be necessary to use a pump in connection with this to get the required pressure.

The steam test consists either of getting up steam to the required pressure in the ordinary way, or by turning it in from another boiler.

While the boiler is under pressure, the hammer test is sometimes employed to determine the condition of the plates. *Light* blows are struck with a hammer on different parts of a plate and the condition of the plate judged from the sound and resistance.

A careful inspection should also be made for defects and indications of weakness, such as a change of form in the shell.

After the test, the boiler should be emptied and the inside carefully inspected, to detect any defective or broken stay-rods; the staybolts should then be tested by means of the hammer test, preferably under air pressure.

BOILER EXPLOSIONS

41. Cause.—Boiler explosions are always due to the fact that some part of the boiler is, for some reason, too weak to withstand the pressure to which it is subjected. This may be due to one of two causes: Either the boiler is not strong enough to safely carry its proper working pressure, or else the pressure has been allowed to rise above the usual point by the sticking of the safety valves, or some similar cause.

42. Elements of Weakness.—A boiler may be unfit to carry its working pressure for one or more of the following reasons: (1) Defective design; (2) defects in workmanship or material; (3) corrosion and general wear and tear; (4) mismanagement in working.

1. *Defective Design.*—This consists, among other things, in designing boilers in such a manner that access cannot be had to the places most liable to wear and tear. Defective

water circulation may also be a result, and this may lead to excessive incrustation and consequent collapse.

2. *Defects of Material and Workmanship.*—The material may be faulty in the first place, the plates containing blisters, laminations, etc., or they may have been burned or injured in flanging, bending, or welding; or they may be scored along the seams by sharp calking tools. The rivets, also, may have been burnt or imperfectly upset. The plates may have been injured in patching, or the patches, if in a firebox, may have been burnt. Also, the greater expansion and contraction of the new plate forming the patch is injurious. Patching a firebox is important work.

3. *Corrosion, Pitting, and Grooving.*—The strength of the shell may be much weakened by these causes. In some boiler explosions, the plates have been found wasted to less than $\frac{1}{16}$ inch.

Fractures, which ultimately end in explosions, may be produced by letting the cold feedwater come directly in contact with the hot plates. The feed should be introduced into the coolest part of the boiler.

4. *Bad Management.*—The pressure of the steam may be allowed to rise above the normal pressure through neglect or through mismanagement. The safety valves may stick fast to their seats due to their not having had proper inspection. The crown sheet, on account of low water, may become overheated to such an extent that the stays pull through and allow the crown sheet to come down, thus causing an explosion.

Should the crown sheet become overheated, close the dampers, smother the fire with fine, wet coal, and open the fire-door a little. Do not start the injector, and do not stop or start the engine or touch the safety valves, as any such change of conditions might cause a sudden increase of pressure that would force the crown sheet down and cause an explosion. Just smother the fire, and allow the crown sheet to cool gradually until it will be safe to begin feeding slowly. If the sheet is found to have become red hot, the engineer should give up his train, as it is impossible to tell just what

damage has occurred without making a close and careful examination.

43. A Source of Danger.—A weak boiler may possibly be exploded by a sudden opening or closing of the throttle valve. That such an explosion is possible is shown by the following experiment made by the United States inspectors: A cylindrical boiler was tested and withstood a steam pressure of 300 pounds without injury. It was then filled again and the steam pressure was run up gradually, the discharge valve being opened at intervals and the fall in pressure noted. When the valve was suddenly opened at a pressure of 235 pounds, the boiler gave way, the iron being twisted and torn into fragments and thrown in all directions. The reason for this was that the sudden rush of steam from the boiler into the discharge pipe reduced the pressure in the boiler very rapidly; this reduction of pressure caused the sudden formation of a great quantity of steam within the water, and the heavy mass of water, being thrown with great violence toward the opening whence the steam was being withdrawn, struck the portions of the boiler near that opening and caused the fracture. Explosions from this cause are probably rare, still it is well to use caution in opening or closing the throttle or safety valves.

The destructive nature of a steam-boiler explosion is due to the enormous amount of energy stored in the steam and heated water. Professor Thurston calculates that 1 cubic foot of water, heated at constant volume until its pressure is 60 to 70 pounds per square inch, has about the same energy as 1 pound of gunpowder, and that the energy stored in a plain cylindrical boiler at 100 pounds pressure is sufficient to project it to a height of over $3\frac{1}{2}$ miles.

44. Violence of Explosion.—If a boiler fractures while undergoing the hydrostatic test, the water escapes through the rent in the plate, and no explosion takes place because the cold water has little or no stored energy. But when a boiler filled with steam and water at high temperature (and pressure) fractures, a violent explosion follows. The steam

escaping through the initial fracture diminishes the pressure on the water in the boiler; the water being at a very high temperature, this diminution of pressure leaves it free to generate instantaneously a new and large volume of steam. The sudden overloading of the boiler due to the extra steam thus formed is what really produces the disastrous effects observed in an explosion. Generally speaking, the larger the body of the contained water, the more disastrous is the result. The safety of water-tube boilers is thus accounted for by the fact that they consist of numerous parts or sections, each containing a relatively small body of water. The bursting of one of these sections is unusual, on account of its small diameter, and should it occur, no disastrous explosion would be likely to follow, on account of the small quantity of water it contains.

Boiler explosions may be prevented by the use of a properly designed and well-made boiler, placed under careful management. The boiler must be regularly inspected, repaired when necessary, and removed from service before becoming so worn out as to be dangerous.

HEAT AND STEAM

INTRODUCTION

WORK AND ENERGY

1. Before taking up the study of locomotive cylinders, valves, and valve gears, it is advisable to make a brief study of work and energy; of heat and temperature; of the effects of heat and the relation between heat and work; also, a study of steam and its properties, and of a simple steam engine. A good knowledge of these subjects will be of great assistance to the student, not only in studying the remainder of this Course, but in his every-day work, as he will understand much better the forces under his control, and what takes place within his engine. He will therefore be better prepared to deal with any emergency that may arise.

WORK

2. Definitions.—In the study of work, a clear conception of the difference between *force*, *work*, and *power* should be gained.

The word **force** is given to that agency which produces, destroys, or changes the direction of motion, or tends to do so. It is given to any pressure, tension, push, or pull, whether applied directly to a body, or, like the force of gravity, through an invisible medium.

Work consists in producing, destroying, or changing the direction of motion in opposition to a resisting force—that is, in moving a body against a resisting force. When water is raised from a well, or earth from a hole in the ground, or,

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in fact, when anything is raised from a lower to a higher level, work is done in overcoming the force of gravity. In bending a board or in driving a nail into it, the positions of some of the molecules of the wood are changed with relation to one another, and the work performed in either case is done in overcoming the resistance that the molecules offer to such change. If a sled is drawn over bare ground, work is done in overcoming the force of friction that acts between the earth and the sled runners to stop the motion of the sled.

If we stop and consider the actions that constitute the work performed by a man, a horse, or a steam engine, we find that *motion* is an essential element. In raising a stone a man does work, since he raises it against the resisting force, gravity; the stone has work done on it, since it is made to move against the action of the force of gravity. If the man were merely to support the stone in his arms, he would do no work in the sense the term is used in mechanics, because, although he supports the stone, he does not move it against the action of a resisting force.

3. Elements of Work.—To do work it is necessary to move a body in opposition to a force that tends to prevent that movement. *Resistance* and *space*, therefore, are essential elements of work. A horse in drawing a load does work, the amount of which depends on the resistance offered to the movement of the load and on the distance through which it is drawn. The amount of work done in raising the weight of a pile driver depends on the height to which it is raised, and on the resistance (the force of gravity) against which it is raised. When the expansive force of steam in a steam cylinder forces out the piston, it does work, the amount of which depends on the distance (length of stroke) through which the force acts and on the resistance against which the piston is moved.

Work cannot be done on a body that offers absolutely no resistance to the action of the force; neither can a body do work unless its motion is resisted by an opposing force. On the other hand, whenever a force produces, destroys, or changes motion, it does work.

4. Unit of Work.—There are many kinds of work, such as raising weights, winding up springs, overcoming frictional resistances, etc., so that in order to be able to measure and compare different kinds of work, it is necessary to have a common unit of measurement. Now, work, as has been seen, consists in producing, destroying, or changing motion against a resistance, and, if the same resistance is encountered, the amount of work expended in effecting the motion will be the same, regardless of whether the motion is vertically upwards or in any other direction. This being true, it is simply necessary to combine a unit of resistance and a unit of space to form a unit of work. One unit of resistance is the pound; a unit of space is the foot; therefore, when these units of length and resistance are used, the unit of work is called the *foot-pound*.

A **foot-pound** represents the amount of work necessary to move a body through a distance of 1 foot against a resisting force of 1 pound. For example, if a 1-pound weight is raised vertically upwards 1 foot, 1 foot-pound of work is done; or, if a steady pull of 1 pound is required to move a sled, 1 foot-pound of work will be expended in moving it 1 foot.

5. Performance of Work.—We may determine the amount of work, in foot-pounds, done in any case by means of the following rule:

Rule.—*The amount of work performed is found by multiplying the resistance, in pounds, by the distance, in feet, through which the body is moved against the action of the resisting force.*

In the case of a locomotive running at constant speed, the resisting force of the train is equal to the drawbar pull, for if it were greater, it would stop the train, and if it were less, the speed would constantly increase; hence, if a locomotive exerts a drawbar pull of, say, 17,000 pounds in moving a train, it does $1 \times 17{,}000 = 17{,}000$ foot-pounds of work for every foot it moves the train; therefore, in traveling 1,000 feet, $1{,}000 \times 17{,}000 = 17{,}000{,}000$ foot-pounds of work will be done on the train.

6. Power.—Power is the rate of doing work. In calculating the amount of work done, the resisting force and the distance the body is moved against it are multiplied together, but the time consumed in doing the work is not taken into consideration.

For example, the amount of work done in raising 500 pounds of wheat 2 feet is the same whether it is raised in 1 minute or in 5 hours. A small child could raise the wheat, lifting a little at a time, and it would do as much work as the man who could raise 100 pounds at a time; but the power of the man, that is, the rate at which he is capable of doing work, is evidently much greater than that of the child.

7. Rate of Doing Work.—By the term *rate of doing work* is meant the amount of work done in a unit of time.

Rule.—*To determine the rate at which work is done, divide the total amount of work, in foot-pounds, by the time, in minutes, required to do the work.*

Example.—An engine, while exerting a constant drawbar pull of 10,000 pounds, travels 12,000 feet in 5 minutes. At what rate is it doing work?

Solution.—The total amount of work done in 5 min. is $10{,}000 \times 12{,}000 = 120{,}000{,}000$ ft.-lb. The rate at which the work is done, therefore, is $120{,}000{,}000 \div 5 = 24{,}000{,}000$ ft.-lb. per min. Ans.

8. Measurement of Work.—The unit of power commonly used to express the rate of doing work is called a **horsepower.** It represents the ability to do 33,000 foot-pounds of work in 1 minute. Thus, if a hoisting engine could just raise 33,000 pounds 1 foot in 1 minute, it would be called a 1-horsepower engine. A 10-horsepower engine can do work at ten times that rate; that is, it can raise 330,000 pounds 1 foot per minute, 33,000 pounds 10 feet per minute, or 3,300 pounds 100 feet per minute. The word "horsepower" is generally abbreviated and written H. P.

Rule.—*To determine the rate, in horsepower, at which work is done, divide the total quantity of work by 33,000 times the number of minutes required to do the work.*

EXAMPLE.—A locomotive, exerting a constant drawbar pull of 15,000 pounds, moves a train 10,000 feet in 10 minutes. At what rate, in horsepower, is the engine doing work?

SOLUTION.—The total quantity of work done is $15{,}000 \times 10{,}000 = 150{,}000{,}000$ ft.-lb.; the rate, in horsepower, is therefore $150{,}000{,}000 \div 33{,}000 \times 10 = 455$ H. P., nearly. Ans.

ENERGY

9. Definition.—Energy is the ability to do work; in other words, it is the ability to produce, destroy, or change motion in opposition to a resisting force. All men and animals possess this power to a greater or less degree. The falling weight of a pile driver, a rolling stone, a car in motion—in fact, any body of matter in motion—is capable of doing work in being brought to rest, and therefore possesses energy.

A body in motion possesses energy because of its motion, and the greater its velocity, the more energy it possesses.

10. Kinetic Energy.—Energy due to the motion of a body is called **kinetic energy,** meaning moving or actual energy. The amount of kinetic energy a body possesses depends on its weight and on the velocity with which it is moving.

Rule.—*To find the kinetic energy of a body, in foot-pounds, multiply the velocity of the body, in feet per second, by itself and by the weight of the body in pounds, and divide the product by 64.32.*

EXAMPLE.—Suppose that a car weighing 40,000 pounds is moving at the rate of 10 feet per second; what energy, in foot-pounds, does it possess?

SOLUTION.—Since its velocity is 10 ft. per sec., and its weight 40,000 lb., the amount of energy that it possesses, at that speed, will be $\frac{10 \times 10 \times 40{,}000}{64.32}$, or about 62,189 ft.-lb., and the car could perform 62,189 ft.-lb. of work in being brought to rest. Ans.

Had the car been moving with a speed of 20 ft. per sec. it would have possessed $\frac{20 \times 20 \times 40{,}000}{64.32}$, or about 248,756 ft.-lb. of energy—four times as much as when traveling at the rate of 10 ft. per sec.

11. Potential Energy.—A body may have no motion, and therefore will possess no kinetic energy, yet, by virtue of an advantage in position, may possess energy of another form. For instance, a pile-driver weight has no energy and can do no work while it is simply resting on the ground, and when held aloft it appears to be just as devoid of energy. That it possesses energy when in the latter position, however, can very readily be proved by allowing it to fall. In fact, there is a great difference between the weight resting on the ground and the weight suspended in the air: in the former position it can do no work; in the latter it can, and its energy, or ability to do work, in the latter case, is due simply to its advantage of position.

It will thus be seen that energy may exist in two widely different forms: (*a*) it may exist as actual motion, as in the case of any mechanical motion, or the invisible motions of the molecules of a body; or, (*b*) it may exist in a stored-up condition, by virtue of the body (as in the case of a raised pile-driver weight), or its molecules (as in the case of a compressed spring), occupying a position or positions of advantage. This stored-up energy is called **potential energy.**

12. Transformation of Energy.—Energy in one form may be transformed into energy of another form. The following is a good illustration of transforming, or changing, kinetic energy into potential energy, and then retransforming it into kinetic energy: Suppose a stone to be thrown straight up in the air. It starts with its greatest velocity (and, therefore, with its greatest amount of kinetic energy), which, as the stone rises, gradually decreases until the stone has attained its greatest height, when the velocity is all spent. For an instant, before starting downwards, the stone is at rest, and therefore for that instant it possesses only potential energy. The kinetic energy with which the stone started was all spent, or used up, in raising the stone to its position of advantage, by virtue of which it possesses its potential energy. In falling, this potential energy is gradually spent in increasing the velocity of the stone and,

therefore, its kinetic energy, until, on reaching its starting point, the stone has regained the same amount of velocity and, therefore, of kinetic energy, it had on starting upwards.

At the instant of beginning and ending its flight the stone possesses only kinetic energy; during its flight it possesses both kinetic and potential energy. The potential energy increases and the kinetic energy decreases as the stone rises while, as it falls, the kinetic energy increases and the potential energy decreases. During every instant of the stone's flight the sum of its kinetic and potential energies is constant, and energy is neither created nor destroyed, but is simply transformed from one form to the other.

There is a certain amount of energy stored in coal in the form of potential energy. When the coal is burned, this energy is liberated and is changed into kinetic energy in the form of heat. The kinetic energy of the heat changes water into steam, which thus has a certain amount of potential energy; when this steam is allowed to act on the piston of a steam engine, causing it to move and overcome a resisting force, its potential energy is changed into kinetic energy, and does work.

13. Conservation of Energy.—The principle of conservation of energy teaches us that energy, like matter, cannot be destroyed, and that the total quantity in the universe remains constant. If a clock is put in motion, the potential energy of the spring is changed into the kinetic energy of motion, which turns the wheels, thus producing friction. This friction produces heat, which is carried away by the surrounding air; but still the energy is not destroyed—it merely exists in another form.

HEAT

14. Definition.—Heat is a form of energy; it is a kind of motion of the molecules composing matter. These molecules are never at rest, but are constantly moving to and fro, bumping and jostling one another in much the same manner as a swarm of bees. It is this movement of the

molecules that produces the sensations of warmth and cold. If the motion is rapid, the body feels warm to the touch; if it is slow, the body feels cold.

TEMPERATURE

15. Definition.—Temperature is a term used to indicate how hot or how cold a body is; that is, to indicate the rate of vibration of the molecules of a body. A hot body is said to have a high temperature; a cold body, a low temperature. When a body receives heat from any source its temperature rises; on the other hand, when a body loses heat its temperature falls.

The term *temperature* does not mean the same as quantity of heat, and the quantity of heat that a body possesses cannot be determined from its temperature. For instance, a cup of water may have a temperature of 212° F., yet it does not possess nearly the quantity of heat that a pail of water at 50° F. does. Again, the cup of water may be at a lower temperature than the water in the pail, in which case it will neither have the temperature nor the quantity of heat of the latter.

Temperature may be considered to be a measure of the velocity of the molecules of a body as they move to and fro, while quantity of heat may be considered to be the energy of the molecules composing the body.

16. Measurement of Temperature.—Temperature is measured by means of an instrument called a **thermometer,** one type of which is shown in Fig. 1. It consists of a glass tube, closed at both ends and having a bulb at the lower end. The bulb and the lower end of the tube are filled with mercury, which, on being heated or cooled, expands or contracts in proportion to the change of temperature. This expansion or contraction causes the top of the mercury column to rise or fall, and since equal changes of temperature make the mercury column rise or fall equal distances, the graduations on the scale are made equal throughout.

In Fig. 1 is shown a **combination thermometer**, that is, one that has two scales. The scale on the left, marked *F*, in combination with the glass tube, forms a *Fahrenheit thermometer* (so named after its inventor), which is the one commonly used; the scale *C* on the right forms, in combination with the glass tube, a *centigrade thermometer*. The centigrade thermometer is used by scientists throughout the world on account of the graduations being better adapted for calculations.

Fig. 1

17. Graduating a Thermometer. — The graduations on the scale of a thermometer are obtained as follows: First, the thermometer is placed in melting ice, and the point to which the mercury column falls is marked and called the *freezing point;* it is next placed in steam that is escaping from an open vessel, and the point to which the mercury rises in the tube is marked and called the *boiling point*. These are two fixed points; that is, the mercury column will always register these same points when the thermometer is placed in broken ice or in steam, under the conditions explained above.

The **freezing point** marks the temperature at which, under atmospheric pressure, water freezes and forms ice, or at which ice melts and forms water, since water freezes and ice melts at exactly the same temperature.

The **boiling point** marks the temperature at which water boils and forms steam, when subjected to atmospheric pressure.

Having these two fixed points, the distance between them is divided into equal parts, the number of divisions depending on whether the scale is for a Fahrenheit or a centigrade thermometer.

18. Fahrenheit Thermometer.—The Fahrenheit thermometer is made by dividing the distance on the scale between the freezing and boiling points into 180 equal

divisions, called *degrees*. The freezing point is marked 32, and the boiling point 212; 32 divisions are marked off from the freezing point downwards, and the lowest one is marked 0; this is called the *zero point* of the scale. The graduations may be extended above the boiling point, or below the zero point, as desired.

Instead of writing the word *degrees* after each reading of temperature, it is customary to represent it by a symbol—a small circle placed above and to the right of the figures. Also, the word *Fahrenheit* is usually represented by the letter F. Thus, 32° F. means the same as though it were written "32 degrees Fahrenheit," and 8° F., the same as "8 degrees Fahrenheit." In this thermometer there are 212 divisions, or degrees, between the zero point and the boiling point.

19. Centigrade Thermometer.—In the centigrade thermometer, the freezing point is marked 0 and the boiling point 100, the distance between the two being divided into 100 equal divisions. As in the Fahrenheit scale, the divisions may be carried above the boiling point and below the zero point. The word *centigrade* is usually abbreviated and written C., as, for example, 10° C., 28° C., etc.

20. Thermometer Readings.—Beginning with 0°, the divisions on both the Fahrenheit and centigrade scales are numbered 1, 2, 3, 4, etc., both above and below the zero point. Therefore, in giving the lower readings of a thermometer, it is necessary to state the number of degrees and whether they are above or below zero. To distinguish temperatures below zero from those above, the sign of subtraction is always placed before the former. Thus, 12° means 12° above zero on both scales, while −12° means 12° below zero.

21. Absolute Temperature.—The freezing point was chosen as the zero point of the centigrade scale. Fahrenheit placed the zero point of his thermometer 32° below the freezing point, as that was the lowest temperature he could obtain, and he supposed that it was impossible to obtain a

lower one. From the results of experiments and from calculations, however, it has been concluded that at 460° F. below zero, or 492° F. below the freezing point, there is absolutely no heat. This is therefore called the *absolute zero*, and all temperatures reckoned from this point are called **absolute temperatures.** Absolute zero has never been reached, the lowest recorded temperature being in the neighborhood of −400° F.

22. Reckoning Absolute Temperature.—Absolute temperature may be reckoned either on the Fahrenheit or on the centigrade scale. Between 0° absolute and 0° F. there are 460 Fahrenheit degrees; between 0° absolute and the freezing point there are 460 + 32 = 492°; while between 0° absolute and the boiling point there are 460 + 212 = 672°. Between 0° absolute and 0° C. there are $273\frac{1}{3}$ centigrade degrees.

Absolute Temperature, Fahrenheit.—If the absolute temperature of a body, in degrees Fahrenheit, is given, its temperature on the ordinary Fahrenheit thermometer can be found by subtracting 460 from the absolute temperature. If the absolute temperature is less than 460, subtract it from 460, and the result will be the temperature below zero on the Fahrenheit thermometer.

The absolute temperature of a body, in degrees Fahrenheit, may be found from its Fahrenheit temperature by adding 460 to it, when the thermometer reading is above zero; if the thermometer reading is below zero, subtract the reading from 460. Thus, 150° F. = 150 + 460 = 610° F. absolute; and, −23° F. = 460 − 23 = 437° F. absolute.

Absolute Temperature, Centigrade.—To find the absolute temperature of a body from its centigrade temperature, add the centigrade temperature to $273\frac{1}{3}$ when it is above zero, and subtract it from $273\frac{1}{3}$ when below zero. Thus, 60° C. = $273\frac{1}{3}$ + 60 = $333\frac{1}{3}$° C. absolute; −10 C. = $273\frac{1}{3}$ − 10 = $263\frac{1}{3}$° C. absolute.

To find the centigrade temperature of a body from its absolute temperature, subtract $273\frac{1}{3}$ from the absolute temperature. Thus, 300° absolute = 300 − $273\frac{1}{3}$ = $26\frac{2}{3}$° C.

If the absolute temperature is less than $273\frac{1}{3}$, subtract the absolute temperature from $273\frac{1}{3}$, and the result will be the centigrade temperature below zero. Thus, 250° absolute $= 273\frac{1}{3} - 250 = 23\frac{1}{3}$° C. below zero.

23. Changing From Centigrade to Fahrenheit. It is frequently necessary to change from one scale to the other. For example, what would 80° C. be on the Fahrenheit scale?

Since the number of degrees between the freezing point and the boiling point on the centigrade scale is 100, and on the Fahrenheit 180, 1° F. will equal $\frac{100}{180}$° C. $= \frac{5}{9}$° C. Likewise, 1° C. will equal $\frac{180}{100}$° F. $= \frac{9}{5}$° F.

Rule.—*Multiply the centigrade temperature by* $\frac{9}{5}$ *and add 32 for the Fahrenheit temperature. If the given temperature is below zero and when multiplied by* $\frac{9}{5}$ *gives a greater product than 32, subtract 32; the result is the Fahrenheit temperature below zero.*

Example.—What will be the reading of a Fahrenheit thermometer if a centigrade thermometer indicates a temperature: (*a*) of 100° C.? (*b*) of −40° C.?

Solution.—(*a*) Applying the rule,

$$100 \times \frac{9}{5} = 180;\ 180 + 32 = 212° \text{ F.} \quad \text{Ans.}$$

(*b*) $40 \times \frac{9}{5} = 72$. Since the given temperature is below zero and its product by $\frac{9}{5}$ is greater than 32,

$$-40° \text{ C.} = 40 \times \frac{9}{5} - 32 = 40° \text{ F. below zero.} \quad \text{Ans.}$$

24. Changing From Fahrenheit to Centigrade. To change Fahrenheit temperatures to their centigrade values.

Rule.—*First of all:* (*a*) *If the given Fahrenheit temperature is 32° or greater, subtract 32 from it;* (*b*) *if between 0° and 32°, subtract it from 32;* (*c*) *if below 0°, add 32 to it. The result, in each case, multiplied by* $\frac{5}{9}$ *will be the centigrade temperature; in the cases of* (*b*) *and* (*c*) *the temperatures will be below zero.*

Example.—What will be the reading on a centigrade thermometer if a Fahrenheit thermometer indicates a temperature: (*a*) of 60° F.? (*b*) of 20° F.? (*c*) of − 20° F.?

SOLUTION.—(*a*) Applying the rule,

$$60 - 32 = 28;\ 28 \times \frac{5}{9} = 15\tfrac{5}{9}°\ \text{C.}\quad \text{Ans.}$$

(*b*) $32 - 20 = 12;\ 12 \times \frac{5}{9} = 6\frac{2}{3}°$ C. below zero. Ans.

(*c*) $20 + 32 = 52;\ 52 \times \frac{5}{9} = 28\frac{8}{9}°$ C. below zero. Ans.

EFFECTS OF HEAT

25. Rise of Temperature.—Suppose that a cylinder *A B*, Fig. 2, fitted with a piston *P*, and half filled with water at a temperature of 34° F., is placed on a fire. Heat will be communicated to the water and will increase the velocity of its molecules; that is, their kinetic energy will increase, and if a thermometer is placed in the water, it will indicate a rise of temperature. One effect of heat, therefore, is to raise the temperature of the body to which it is applied.

26. Expansion of Body.—After a certain temperature is reached, the molecules of the water not only move faster but they separate farther from one another, and their paths are longer. Since the molecules are farther apart, it follows that the water must occupy more space than formerly, or, in other words, it expands. This expansion will be indicated by the piston *P* rising as the water is heated. Another effect of heat, therefore, is to expand the body to which it is applied. Other familiar examples of the expansion of bodies due to heat are as follows: The tires on locomotives are bored smaller than the wheel centers on which they are to fit, and are then expanded by the application of heat until they will go on; on cooling they contract again, and grip the wheel very firmly. Also, the rails of a railway are considerably longer in summer than in winter, due to expansion caused by the increase in temperature.

Generally, the greater part of the heat given to a body is spent in raising its temperature, and but little goes to expand the body.

27. Limit of Temperature.—Suppose that the piston, Fig. 2, is now removed from the cylinder, and that a

thermometer is suspended in the water. As heat is applied to the cylinder, the thermometer will show a gradual rise in temperature until 212° F. is reached, after which the temperature will remain constant, no matter how much heat is applied. Before 212° F. is reached, most of the heat is spent in raising the temperature of the water, and but little in increasing the distance between its molecules; afterwards, however, all the heat is used in overcoming the attraction of the molecules for one another, and in separating them so far that they no longer attract, but actually repel one another. In other words, the heat is used in changing the water into a vapor called *steam*.

FIG. 2

If a block of ice at a temperature lower than 32° F. is heated, its temperature will gradually rise until 32° F. is reached, when it will remain stationary. The ice will then begin to melt and the heat applied to it, instead of increasing its temperature, is all used in internal work effecting this change of state. Here, then, is another effect of heat; it will change a solid into a liquid, or a liquid into a gas or vapor.

28. Sensible Heat and Latent Heat.—That part of the heat that goes to raise the temperature of a body and, therefore, affects the thermometer is called **sensible heat;** that which is expended on the molecules of a body in changing it from a solid to a liquid, or from a liquid to a vapor, but does not affect its temperature, is called **latent heat.**

MEASUREMENT OF HEAT

29. Unit of Heat.—Heat cannot be measured directly in pounds or gallons, or by any like units, but must be measured by the effects that it produces. The usual method is to measure the change of temperature it produces in

a known weight of water. To measure heat there must be a unit of measurement, and this unit is called a *heat unit*, or *British thermal unit*, this latter being abbreviated "B. T. U."

A **heat unit** is the quantity of heat required to raise the temperature of 1 pound of water through 1° Fahrenheit. Thus, 1 heat unit will raise the temperature of 1 pound of water 1° F., 2 pounds $\frac{1}{2}$° F., or 10 pounds $\frac{1}{10}$° F.; 10 heat units will raise the temperature of 1 pound of water 10° F., 10 pounds 1° F., or 20 pounds $\frac{1}{2}$° F., etc

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RELATION BETWEEN HEAT AND WORK

30. Suppose that the piston, Fig. 2, had been allowed to remain in the cylinder while the water was being changed into steam. Steam at 212° F. occupies nearly 1,700 times the space that its water originally occupied; hence, the piston will be lifted in the cylinder to make room for the steam that is being formed. To raise the piston, however, work must be done; here, then, is an example of work being done by heat.

On the other hand, work will produce heat. If two blocks of wood are rubbed briskly together, they will become warm, and may even ignite and burn. The work of friction causes the journals and bearings of fast-running machines to heat. An iron rod may be raised to a considerable heat by pounding it on an anvil. The work done by the driver brake in holding back the engine on a down grade generates heat that raises the temperature of the tires; and, if the brakes are held on for a sufficient length of time, the heat generated will expand the tires until they become loose on the driving wheels.

Since work may be changed into heat, and heat into work, it seems probable that some fixed ratio exists between the unit of heat and the unit of work. By a careful series of experiments, Doctor Joule, of England, discovered this ratio. He found that 1 unit of heat would do 772 foot-pounds of work; later and more accurate experiments, however, show

that 1 heat unit will do 778 foot-pounds of work. The quantity 778 foot-pounds is called the **mechanical equivalent** of 1 heat unit, or **Joule's equivalent.**

Experiment has shown, therefore, that heat can be converted into work, or work into heat; that 778 foot-pounds of work, if converted into heat, will produce 1 unit of heat, or that 1 heat unit will do 778 foot-pounds of work.

STEAM

31. Definition.—Steam is a colorless water vapor; that is, it is water changed into a gaseous state by the application of heat. The process of changing water into steam by the application of heat is called *ebullition*, or *boiling*.

When water is heated in a vessel, the air contained in the water is first driven off—some escaping from the surface, and some collecting in bubbles on the sides of the vessel. As the temperature of the water approaches the boiling point, bubbles of steam form at the heating surface and rise until they meet the upper and cooler portions of the water, when they collapse with a slight sound. This sound is produced by the steam bubbles condensing, allowing the surrounding water to come violently together. The "singing" of a teakettle, as it is termed, which occurs just before it begins to boil, is caused by the collapsing of a large number of steam bubbles.

As soon as the upper portions of water become sufficiently heated, the bubbles cease to collapse; they grow slightly larger as they rise, and on nearing the surface explode and throw small particles of water up into the steam space. This causes the violent agitation of the surface of the water known as boiling—a sure sign that the water is being converted into steam.

Water then may be converted into steam by imparting heat to it. Steam, on the other hand, may be condensed or changed back into water by abstracting heat from it. The latter process is called *condensing*, and the water regained is called *water of condensation*.

32. Saturated Steam.—The term "saturated," when applied to steam, does not have the same meaning as when applied to a sponge; that is, it is not intended to convey the idea that the steam is saturated with water. Steam is called **saturated steam** when it is at the greatest density and pressure corresponding to its temperature, under which condition it contains just sufficient heat to maintain it in the state of steam. While in this state, any increase of pressure or loss of heat will cause some of it to condense. This is the condition of steam in a boiler.

Since saturated steam is in that critical state whereby a slight change of pressure or loss of heat will reconvert some of it into water, it has not the permanent condition of a true gas, the physical state of which is unaffected either by a change of pressure or by a loss of heat, or by both. Saturated steam, consequently, does not follow the "laws of gases."

The temperature of saturated steam depends on the pressure only; that is, for every pressure it has a definite temperature, and this temperature is always the same as that of the water with which it may be in contact.

On account of this property, the temperature of the steam in a boiler may be determined from the steam-gauge reading, or the pressure of the steam may be determined from its temperature, provided that the relations between temperature and pressure are known. These relations have been determined by experiment throughout a wide range of pressures, and are given in Table I.

33. Superheated Steam.—Superheated steam is steam whose temperature is higher than that corresponding to its pressure as given in Table I. Saturated steam may be superheated in two ways: (*a*) by separating it from water and imparting additional heat to it; or, (*b*) by allowing it to expand without doing work, in which case superheated steam of a lower pressure will be formed.

Steam cannot be superheated while in contact with water, owing to the fact that any heat added will go to form more

saturated steam, without affecting the temperature of that already formed. Neither can superheated steam exist in the presence of water. If too much water is not present, a sufficient part of the excess heat of the steam will be used to evaporate and superheat it, thereby reducing the excess of heat. If there is too much water for the excess heat to evaporate, the steam will be reduced to the point of saturation, the superheat being entirely used up in converting the water into saturated steam.

Saturated steam is not a true gas, although, as has been found by experiment, when superheated about 20° F. it behaves very nearly like a true gas. If saturated steam suffers any loss of heat, some of it will condense. Superheated steam, on the other hand, must lose all of its excess heat before condensation commences. There are many locomotives in service where the steam on its way from the boiler to the steam chest is superheated. Usually the firebox gases pass through large flues so that the heat is not absorbed by the water before it reaches the superheater, which gives a high degree of superheat.

34. Wet and Dry Steam.—Steam, unless superheated, always contains more or less moisture in the form of minute particles or spray mixed with it. It is the amount of moisture that steam contains that determines whether it is to be called *wet* or *dry*. Strictly speaking, only superheated steam is dry, since, in practice, saturated steam always contains some moisture; yet the term "dry" is not applied to the former, but is intended to indicate the condition of saturated steam.

Wet steam is steam that contains considerable moisture mixed with it in the form of minute spray.

Dry steam, in the usual meaning of the term, is steam that contains but very little moisture in suspension. In practice, steam containing less than 3 per cent. of moisture is considered as dry; steam containing more than 3 per cent. is considered as wet steam. Superheated steam contains no moisture whatever.

Dry saturated steam and superheated steam are colorless, while wet steam, owing to the amount of water spray it contains, appears white. The condition of the steam in a boiler, therefore, can be judged to some extent by the appearance of a jet of steam issuing from a small orifice situated some distance above the water in the boiler.

Superheated steam will be transparent for a couple of inches from the orifice, after which it will gradually change to a bluish, and then to a grayish-white color, depending on its distance from the orifice.

Dry steam has a very faint bluish color at the orifice, which gradually changes to a grayish-white as its distance from the orifice increases.

Wet steam has a dense white appearance from the moment it leaves the orifice, and its appearance does not change much thereafter.

35. Wiredrawn Steam.—When steam has its pressure reduced in passing through a contraction in a valve, steam port, or steam passage, it is said to be **wiredrawn,** or *throttled.* Partly closing a steam valve or the throttle of an engine, therefore, wiredraws the steam passing through it, and the more the valve or throttle is closed, the more the steam is wiredrawn.

The wiredrawing of steam tends to superheat it; therefore, if the steam supplied to an engine is wet, it will often be found advisable to wiredraw it by partly closing the throttle.

36. Properties of Saturated Steam.—Saturated steam possesses a number of *properties* that change as the pressure of the steam is changed. These properties are as follows:

1. The temperature of the steam.

2. The heat of the liquid. By this term is meant the number of heat units required to raise 1 pound of water at 32° F. to the temperature of the steam.

3. The latent heat of vaporization, or, as it is usually called, latent heat. Latent heat was defined in Art. **28.** By latent heat of vaporization is meant the number of heat

TABLE I

TABLE OF THE PROPERTIES OF SATURATED STEAM

Pressure Above Vacuum Pounds per Square Inch	Temperature Degrees Fahrenheit	Quantities of Heat British Thermal Units			Weight of a Cubic Foot of Steam Pounds	Volume	
		Required to Raise Temperature of the Water From 32° to the Given Temperature	Total Latent Heat at the Given Pressure	Total Heat Above 32°		Of a Pound of Steam Cubic Feet	Ratio of Volume of Steam to Volume of Equal Weight of Distilled Water at Temperature of Maximum Density
1	2	3	4	5	6	7	8
1	102.018	70.040	1,043.015	1,113.055	.003027	330.400	20,623.0
2	126.302	94.368	1,026.094	1,120.462	.005818	171.900	10,730.0
3	141.654	109.764	1,015.380	1,125.144	.008522	117.300	7,325.0
4	153.122	121.271	1,007.370	1,128.641	.011172	89.510	5,588.0
5	162.370	130.563	1,000.899	1,131.462	.013781	72.560	4,530.0
6	170.173	138.401	995.441	1,133.842	.016357	61.140	3,816.0
7	176.945	145.213	990.695	1,135.908	.018908	52.890	3,302.0
8	182.952	151.255	986.485	1,137.740	.021436	46.650	2,912.0
9	188.357	156.699	982.690	1,139.389	.023944	41.770	2,607.0
10	193.284	161.660	979.232	1,140.892	.026437	37.830	2,361.0
11	197.814	166.225	976.050	1,142.275	.028911	34.590	2,159.0
12	202.012	170.457	973.098	1,143.555	.031376	31.870	1,990.0
13	205.929	174.402	970.346	1,144.748	.033828	29.560	1,845.0
14	209.604	178.112	967.757	1,145.869	.036265	27.580	1,721.0
14.7	212.000	180.531	966.069	1,146.600	.037928	26.370	1,646.0
15	213.067	181.608	965.318	1,146.926	.038688	25.850	1,614.0
16	216.347	184.919	963.007	1,147.926	.041109	24.330	1,519.0
17	219.452	188.056	960.818	1,148.874	.043519	22.980	1,434.0
18	222.424	191.058	958.721	1,149.779	.045920	21.780	1,359.0
19	225.255	193.918	956.725	1,150.643	.048312	20.700	1,292.0
20	227.964	196.655	954.814	1,151.469	.050696	19.730	1,231.0
22	233.069	201.817	951.209	1,153.026	.055446	18.040	1,126.0
24	237.803	206.610	947.861	1,154.471	.060171	16.620	1,038.0
26	242.225	211.089	944 750	1,155.819	.064870	15.420	962.3
28	246.376	215.293	941.791	1,157.084	.069545	14.380	897.6
30	250.293	219.261	939.019	1,158.280	.074201	13.480	841.3
32	254.002	223.021	936.389	1,159.410	.078839	12.680	791.8
34	257.523	226.594	933.891	1,160.485	.083461	11.980	748.0
36	260.883	230.001	931.508	1,161.509	.088067	11.360	708.8
38	264.093	233.261	929.227	1,162.488	.092657	10.790	673.7
40	267.168	236.386	927.040	1,163.426	.097231	10.280	642.0
42	270.122	239.389	924.940	1,164.329	.101794	9.826	613.3
44	272.965	242.275	922.919	1,165.194	.106345	9.403	587.0
46	275.704	245.061	920.968	1,166.029	.110884	9.018	563.0
48	278.348	247.752	919.084	1,166.836	.115411	8.665	540.9

1	2	3	4	5	6	7	8
50	280.904	250.355	917.260	1,167.615	.119927	8.338	520.5
52	283.381	252.875	915.494	1,168.369	.124433	8.037	501.7
54	285.781	255.321	913.781	1,169.102	.128928	7.756	484.2
56	288.111	257.695	912.118	1,169.813	.133414	7.496	467.9
58	290.374	260.002	910.501	1,170.503	.137892	7.252	452.7
60	292.575	262.248	908.928	1,171.176	.142362	7.024	438.5
62	294.717	264.433	907.396	1,171.829	.146824	6.811	425.2
64	296.805	266.566	905.900	1,172.466	.151277	6.610	412.6
66	298.842	268.644	904.443	1,173.087	.155721	6.422	400.8
68	300.831	270.674	903.020	1,173.694	.160157	6.244	389.8
70	302.774	272.657	901.629	1,174.286	.164584	6.076	379.3
72	304.669	274.597	900.269	1,174.866	.169003	5.917	369.4
74	306.526	276.493	898.938	1,175.431	.173417	5.767	360.0
76	308.344	278.350	897.635	1,175.985	.177825	5.624	351.1
78	310.123	280.170	896.359	1,176.529	.182229	5.488	342.6
80	311.866	281.952	895.108	1,177.060	.186627	5.358	334.5
82	313.576	283.701	893.879	1,177.580	.191017	5.235	326.8
84	315.250	285.414	892.677	1,178.091	.195401	5.118	319.5
86	316.893	287.096	891.496	1,178.592	.199781	5.006	312.5
88	318.510	288.750	890.335	1,179.085	.204155	4.898	305.8
90	320.094	290.373	889.196	1,179.569	.208525	4.796	299.4
92	321.653	291.970	888.075	1,180.045	.212892	4.697	293.2
94	323.183	293.539	886.972	1,180.511	.217253	4.603	287.3
96	324.688	295.083	885.887	1,180.970	.221604	4.513	281.7
98	326.169	296.601	884.821	1,181.422	.225950	4.426	276.3
100	327.625	298.093	883.773	1,181.866	.230293	4.342	271.1
105	331.169	301.731	881.214	1,182.945	.241139	4.147	258.9
110	334.582	305.242	878.744	1,183.986	.251947	3.969	247.8
115	337.874	308.621	876.371	1,184.992	.262732	3.806	237.6
120	341.058	311.885	874.076	1,185.961	.273500	3.656	228.3
125	344.136	315.051	871.848	1,186.899	.284243	3.518	219.6
130	347.121	318.121	869.688	1,187.809	.294961	3.390	211.6
135	350.015	321.105	867.590	1,188.695	.305659	3.272	204.2
140	352.827	324.003	865.552	1,189.555	.316338	3.161	197.3
145	355.562	326.823	863.567	1,190.390	.326998	3.058	190.9
150	358.223	329.566	861.634	1,191.200	.337643	2.962	184.9
160	363.346	334.850	857.912	1,192.762	.358886	2.786	173.9
170	368.226	339.892	854.359	1,194.251	.380071	2.631	164.3
180	372.886	344.708	850.963	1,195.671	.401201	2.493	155.6
190	377.352	349.329	847.703	1,197.032	.422280	2.368	147.8
200	381.636	353.766	844.573	1,198.339	.443310	2.256	140.8
210	385.759	358.041	841.556	1,199.597	.464295	2.154	134.5
220	389.736	362.168	838.642	1,200.810	.485237	2.061	128.7
230	393.575	366.152	835.828	1,201.980	.506139	1.976	123.3
240	397.285	370.008	833.103	1,203.111	.527003	1.898	118.5
250	400.883	373.750	830.459	1,204.209	.547831	1.825	114.0
260	404.370	377.377	827.896	1,205.273	.568626	1.759	109.8
270	407.755	380.905	825.401	1,206.306	.589390	1.697	105.9
280	411.048	384.337	822.973	1,207.310	.610124	1.639	102.3
290	414.250	387.677	820.609	1,208.286	.630829	1.585	99.0
300	417.371	390.933	818.305	1,209.238	.651506	1.535	95.8

units required to change 1 pound of water at the boiling temperature into steam at the same temperature.

4. The total heat of vaporization, or, simply, total heat. By this is meant the number of heat units required to raise the temperature of 1 pound of water at 32° F. to the boiling point, and to convert it into steam of the temperature and pressure in question. The total heat is equal to the sum of the heat of the liquid and the latent heat.

5. The specific volume of the steam. This is the space, in cubic feet, that 1 pound of steam at the given pressure occupies.

6. The density of the steam. This is the weight of 1 cubic foot of steam at the given pressure.

All the foregoing properties are different for different pressures. For instance, if water boils under atmospheric pressure, its temperature and the temperature of the steam generated is 212° F.; the heat of the liquid is 180.531 heat units; the latent heat, 966.069 heat units; the total heat, 1,146.6 heat units. A pound of steam at this pressure occupies 26.37 cubic feet of space, and a cubic foot of the steam therefore weighs $\frac{1}{26.37}$, or .038 pound, nearly.

When the pressure is 70 pounds per square inch above vacuum (70 – 14.7, or 55.3 pounds gauge), the temperature is 302.774° F.; the heat of the liquid is 272.657 heat units; the latent heat is 901.629 heat units; and the total heat is 1,174.286 heat units. A pound of steam at this pressure occupies 6.076 cubic feet, and a cubic foot of steam therefore weighs $\frac{1}{6.076}$, or .164584 pound.

The properties of saturated steam have been determined by direct experiment for all ordinary steam pressures, and are given in Table I.

37. Explanation of the Steam Table.—*Column 1.* This column gives absolute pressures (see *Boiler Attachments*, Part 1) from 1 to 300 pounds. These pressures being reckoned from the point of vacuum are consequently

14.7 pounds greater than gauge pressure; hence, in using this table, care must be taken not to use a gauge pressure without first adding 14.7 pounds to it.

When the gauge registers 0 pound pressure, the corresponding absolute pressure is 14.7 pounds. Therefore, all pressures in column 1 below 14.7 are less than 0 gauge pressure. For example, 14 pounds absolute is about .7 pound below atmospheric pressure and represents nearly $1\frac{1}{2}$ inches of vacuum; 6 pounds absolute represents about 18 inches of vacuum, while 1 pound absolute represents about 28 inches of vacuum. In other words, 1 pound absolute is 1 pound above vacuum, and nearly 14 pounds below 0 gauge pressure (see *Boiler Attachments*, Part 1). Pressures above 14.7 pounds, on the other hand, are above atmospheric pressure, and consequently are registered on the gauge. For example, a correct gauge, subjected to 20 pounds absolute pressure, will register 5.3 pounds; under 30 pounds absolute it will register 15.3 pounds, and so on for the other pressures.

Column 2.—Column 2 gives the temperatures at which water will boil—and, therefore, the temperature of the steam generated—when subjected to the corresponding pressure in column 1. By comparing columns 1 and 2 it will be seen that, as the pressure is increased from 1 to 300 pounds absolute, the boiling point increases from 102° F. to 417° F.

Column 3.—Column 3 gives the heat of the liquid under the different pressures. For instance, 108.531 heat units is necessary to raise the temperature of 1 pound of water at 32° F. to the boiling point (212° F.) under an absolute pressure of 14.7 pounds, and 250.355 heat units to raise it to the boiling point (280.904°) under 50 pounds absolute pressure.

It will be noticed that the values in column 3 may be obtained approximately, by subtracting 32 from the corresponding temperature in column 2. If it required exactly 1 heat unit to raise the temperature of 1 pound of water 1° F. at all temperatures, it would, of course, take exactly $212 - 32 = 180$ heat units to raise 1 pound of water from 32° F. to 212° F. Experiment, however, shows that above

62° F. an amount slightly greater than 1 heat unit is necessary, as will be seen by comparing columns 2 and 3.

Column 4.—Column 4 gives the latent heat of the steam. By comparing columns 1 and 4 it will be observed that the latent heat decreases slightly as the pressure increases.

Column 5.—Column 5 gives the total heat of vaporization. It will be seen that the values in this column may be obtained by adding together the corresponding values in columns 3 and 4.

Column 6.—Column 6 gives the density or weight of a cubic foot of steam, in pounds, under the different pressures. As will be noticed, the weight increases with the pressure. The reason for this is that a pound of steam is forced to occupy less and less space as the pressure is increased (see column 7) and thus the amount, and therefore weight, of steam in each cubic foot of space increases with the pressure.

Column 7.—Column 7 gives the space, in cubic feet, occupied by 1 pound of steam under the different pressures. This decreases greatly with the pressure, decreasing from 330.4 cubic feet at 1 pound absolute to 1.535 cubic feet at 300 pounds absolute. It will be noticed that the corresponding values of columns 6 and 7 multiplied together always produce 1. For example, in columns 6 and 7, opposite to 46 of column 1, we find the values .110884 and 9.018, which multiplied together produce 1, very nearly.

Column 8.—Column 8 gives the ratio of the volume of 1 pound of steam at the given pressure to the volume of 1 pound of water at 39.1° F., at which temperature water is at its greatest density. The values in column 8 may be obtained by dividing 62.425—the weight of a cubic foot of water at 39.1° F.—by the corresponding numbers in column 6.

In using Table I it must be remembered: first, that the pressures in column 1 are absolute pressures, and that consequently 14.7 pounds must be added to gauge pressure before it can be used with the table; and second, that the heat of the liquid (column 3), the latent heat (column 4), and the total heat (column 5) are calculated from 32° F., and not from 0° F.

EXAMPLES ON THE USE OF THE STEAM TABLE

EXAMPLE 1.—Give the values of the different properties of saturated steam at 145.3 pounds gauge pressure.

SOLUTION.—A gauge pressure of 145.3 lb. corresponds to an absolute pressure of 160 lb.; therefore, from Table I we find that at 160 lb. absolute the temperature of the steam is 363.346° F.; the heat of the liquid, 334.850 heat units; the latent heat, 857.912 heat units; and the total heat, 1,192.762 heat units. Ans.

EXAMPLE 2.—Calculate the heat required to change 5 pounds of water at 32° F. into steam at 92 pounds pressure above vacuum.

SOLUTION.—From column 5, the total heat of 1 lb. of steam at 92 lb. pressure, absolute, is 1,180.045 heat units; therefore, the total heat of 5 lb. will be $1{,}180.045 \times 5 = 5{,}900.225$ heat units. Ans.

EXAMPLE 3.—How many heat units are required to raise $8\frac{1}{2}$ pounds of water from 32° F. to 250° F.?

SOLUTION.—The heat of the liquid of 1 lb. at 250.293° F. is 219.261 heat units (see columns 2 and 3). Now, since 1 heat unit will raise the temperature of 1 lb. of water 1°, .293 heat unit must have been necessary to raise the water from 250° F. to 250.293° F. To find the heat of the liquid at 250° F., therefore, subtract .293 from the 219.261 heat units. $219.261 - .293 = 218.968$ heat units for 1 lb.; $8\frac{1}{2} \times 218.968 = 1{,}861.228$ heat units for $8\frac{1}{2}$ lb. Ans.

EXAMPLE 4.—How many foot-pounds of work will it require to change 60 pounds of boiling water, at 80 pounds absolute pressure, into steam of the same pressure?

SOLUTION.—Looking in column 4, the latent heat of vaporization is 895.108; that is, it takes 895.108 heat units to change 1 lb. of water at 80 lb. pressure into steam of the same pressure. Therefore, it takes $895.108 \times 60 = 53{,}706.48$ heat units to perform the same operation on 60 lb. of water. Now, since 1 heat unit equals 778 ft.-lb. of work (Art. **36**), $53{,}706.48 \times 778 = 41{,}783{,}641.44$ ft.-lb. will be required. Ans.

EXAMPLE 5.—Find the volume occupied by 14 pounds of steam at 30 pounds gauge pressure.

SOLUTION.— 30 lb. gauge pressure is $30 + 14.7 = 44.7$, say 45, lb. absolute pressure. The volume of a pound of steam at 44 lb. pressure is 9.403 cu. ft.; that of a pound of steam at 46 lb. pressure is 9.018 cu. ft. $9.403 - 9.018 = .385$ cu. ft., the difference in volume for a difference in pressure of 2 lb. $\frac{.385}{2} = .1925$ cu. ft., the difference in volume for a difference of 1 lb. By subtracting this from the volume of 1 lb.

of steam at 44 lb. pressure, we have the volume at 45 lb. Therefore, $9.403 - .1925 = 9.2105$ cu. ft. is the volume of 1 lb. of steam at 45 lb. pressure. The .1925 is subtracted from 9.403, since the volume is less for a pressure of 45 lb. than for 44 lb.; 14 lb., therefore, will occupy $14 \times 9.2105 = 128.947$ cu. ft. Ans.

EXAMPLE 6.—Find the weight of 40 cubic feet of steam at a temperature of 254° F.

SOLUTION.—The weight of 1 cu. ft. of steam at 254.002° is, from the table, .078839 lb. Neglecting the .002°, the weight of 40 cu. ft. is therefore $40 \times .078839 = 3.15356$ lb. Ans.

EXAMPLE 7.—How many pounds of steam at 64 pounds pressure absolute are required to raise the temperature of 300 pounds of water from 40° F. to 130° F., the water and steam being mixed together?

SOLUTION.—The number of heat units necessary to raise 1 lb. from 40° to 130° F. is $130 - 40 = 90$ heat units. (Actually a little more would be required, but the above is near enough for all practical purposes.) Now, to raise the temperature of 300 lb. of water from 40° to 130°, the steam must supply $90 \times 300 = 27{,}000$ heat units. It does this by being condensed and then having its water of condensation reduced to 130° F. 1 lb. of steam at 64 lb. pressure gives up, in condensing to 1 lb. of water, its latent heat of vaporization, or 905.9 heat units. In addition to this, its water of condensation gives up 166.805 heat units in being reduced to 130° F. This is found as follows: The water of condensation has the same temperature as the steam, 296.805° F. For every degree that its temperature is reduced, each pound gives up practically 1 heat unit. In falling from 296.805° to 130°, each pound gives up $296.805 - 130 = 166.805$ heat units. Each pound of steam, therefore, gives up a total of $905.9 + 166.805 = 1{,}072.705$ heat units; hence, it will require $\frac{27{,}000}{1{,}072.705} = 25.17$ lb. of steam to raise the 300 lb. of water from 40° to 130° F. Ans.

THE LOCOMOTIVE

THE STEAM ENGINE

DESCRIPTION AND PARTS

WORK DONE BY STEAM

1. Strictly speaking, steam does not perform work; it simply acts as an agent by means of which the potential energy of the fuel is converted into kinetic energy and made to do work. Potential energy is stored-up energy; kinetic energy is energy of motion. A form of potential energy is energy stored up in coal. When it is liberated by the process of burning, it is changed into heat and is then called kinetic energy. When water is changed into steam by heat, its kinetic energy is its expansive power.

The ability to do work that steam possesses is therefore due entirely to its heat; in other words, it is the heat that does the work and not the steam. However, as it is customary to speak of the "work done by steam," "the work done by steam in expanding," etc., these expressions will be used instead of the longer one, "the work done by the heat contained in steam."

The usual method of obtaining work from steam is to generate it in a closed boiler at from 75 to 200 pounds pressure. This steam is then admitted first to one end of a cylinder fitted with a piston, and then to the other. The pressure of the steam is thus applied alternately on opposite sides of the piston, with the result that it is made to move to and fro within the cylinder.

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THE STEAM CYLINDER

2. Description.—The working of a steam cylinder can best be explained by referring to Fig. 1, in which *C* is the cylinder, shown in section; *P*, the piston, which makes a steam-tight joint with the walls of the cylinder; *R*, the piston

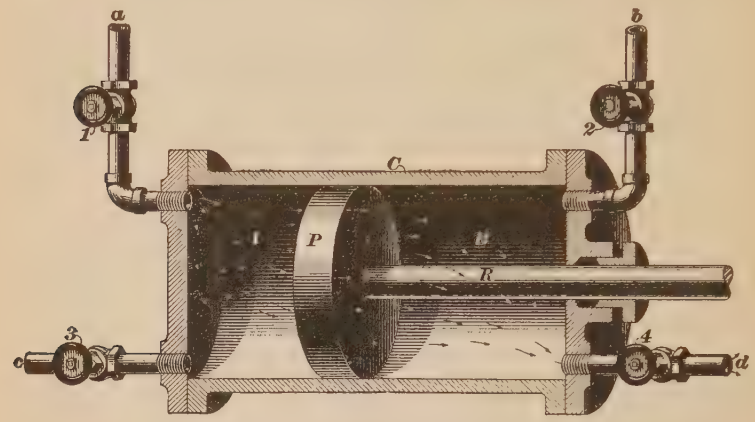


FIG. 1

rod; *a* and *b*, two steam pipes that connect the ends *A* and *B* of the cylinder with the boiler; and *c* and *d*, two short pipes that connect the ends *A* and *B* of the cylinder with the atmosphere. The passages in the pipes *a*, *b*, *c*, and *d* are controlled by the valves *1*, *2*, *3*, and *4*.

3. Generating Power.—It is evident that the valves *1* and *2* should not be open at the same time, since in that case both sides of the piston will be acted on by steam at boiler pressure. Suppose that valve *1* is opened and that valves *2*, *3*, and *4* remain closed. Under these conditions, steam will enter the left end *A* of the cylinder and force the piston to the right until the air that is entrapped in the end *B* is compressed sufficiently to stop the piston. The piston, therefore, cannot complete its stroke until the air under compression in the end *B* is allowed to escape by opening the valve *4*.

To make the piston take a stroke to the right, therefore, it is necessary to close valves *2* and *3*, and open valves *1*

and *1*. Likewise, to make it take a stroke to the left it is necessary to close valves *1* and *1* and open valves *2* and *3*. In either case, while steam is being admitted to the cylinder on one side of the piston, it must be exhausted from it on the other side. The entering steam exerts a greater pressure on the piston than does the steam being exhausted; consequently, the piston always moves toward that end of the cylinder that is open to the atmosphere through the exhaust passage.

STEAM CHEST AND SLIDE VALVE

4. Description of the Steam Chest and Ports.—In order that the piston may be made to move regularly back and forth in the cylinder, some means must be provided

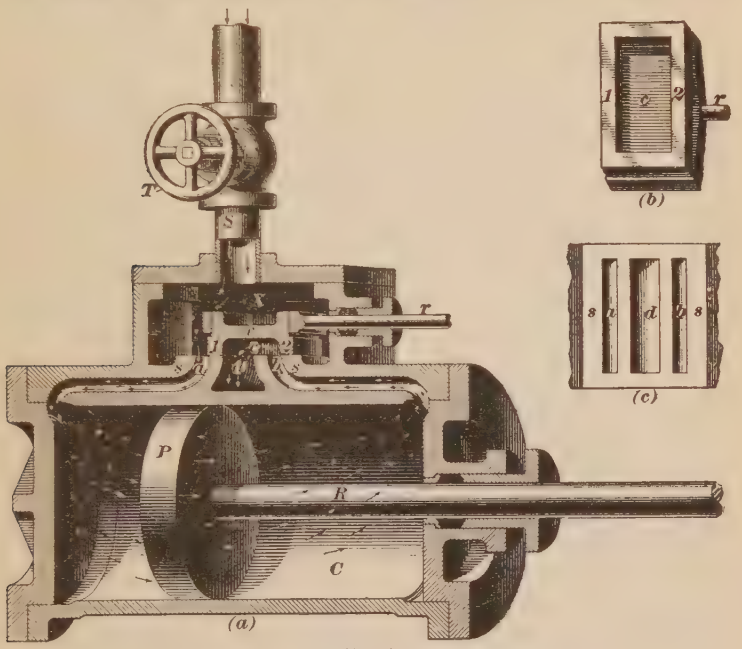


FIG. 2

whereby the steam can be admitted to, and exhausted from, the cylinder regularly and at the proper moment; a simple device for accomplishing this is illustrated in Fig. 2. In (*a*)

make the illustration as simple as possible, that it may be more readily understood.

It is desirable to convert or change the to-and-fro motion of the piston of an engine into rotary motion, as in turning the flywheel of a stationary engine, or the drivers of a locomotive. This is accomplished by means of a connecting-rod G and crank K, Fig. 3. It is essential, also, that the engine be self-acting when once started, and this is accomplished by giving the slide valve the proper to-and-fro motion by means of the valve rod g and the crank k on the shaft. Motion is communicated by the piston P, through the piston rod R and connecting-rod G, to the crank K, and by this means the shaft D and, consequently, the crank k are rotated. The motion of the crank k is communicated through the valve rod g and valve stem r to the slide valve, which is made to slide to and fro on its seat. We shall, for convenience, allude to K and k as the piston crank and valve crank, respectively.

The valve crank k is secured to the shaft D at right angles to the position of the crank K; consequently, the slide valve is at mid-stroke* when the piston is at either end of its stroke.

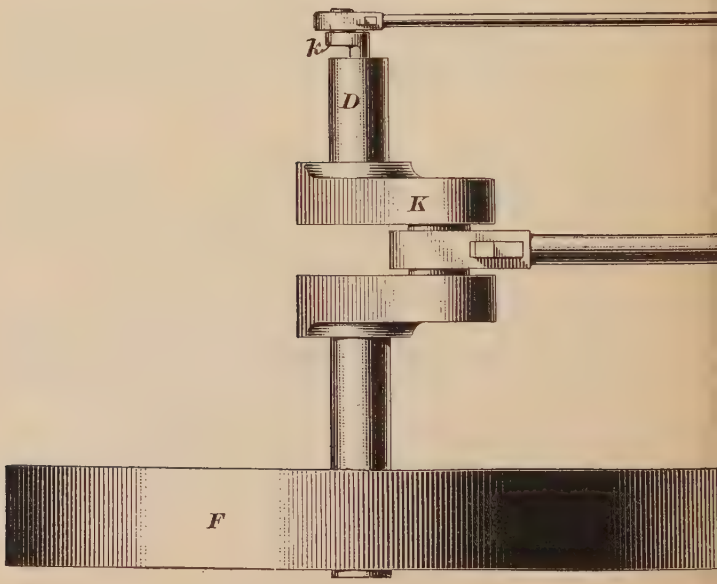
To show the relative positions of the slide valve and piston for different points of both an outward and a return stroke of the piston, the following series of diagrams are given.

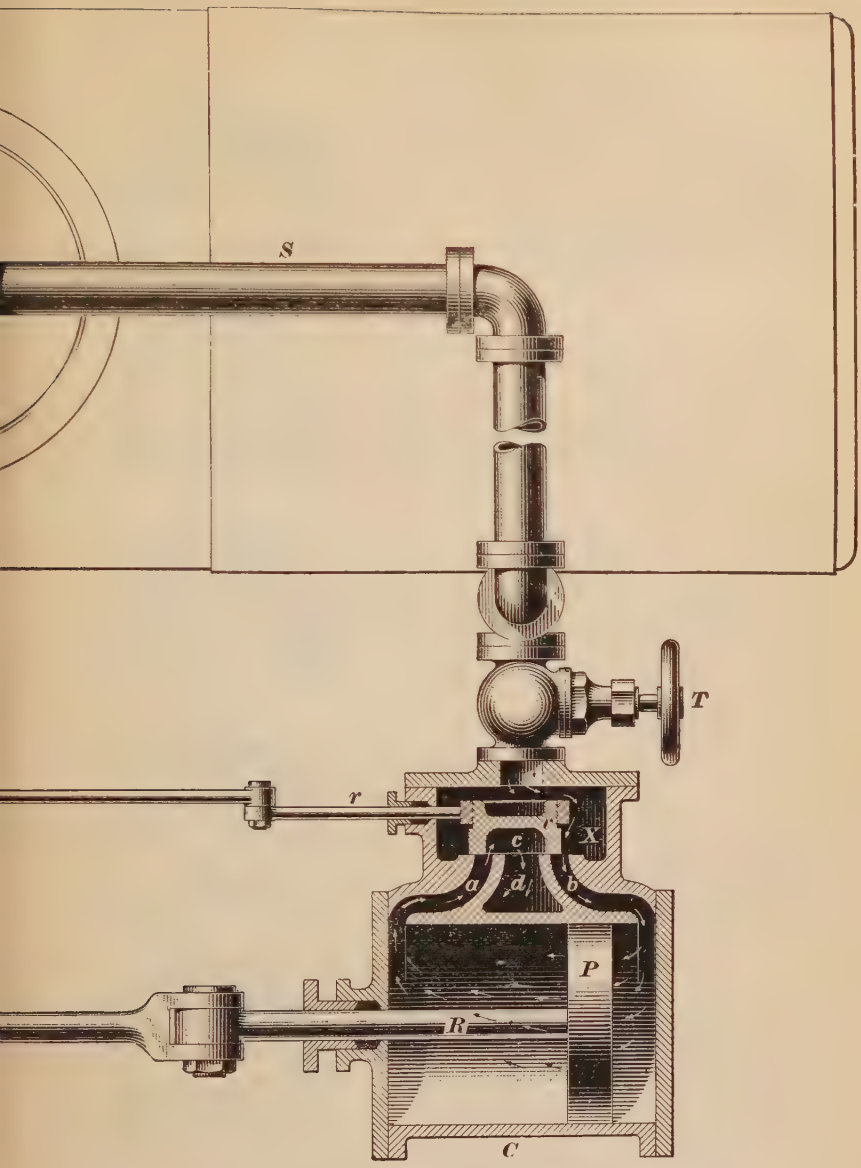
DIAGRAMS OF A SLIDE-VALVE ENGINE

9. Explanation of Diagrams.—In the five diagrams of a slide-valve engine, Fig. 4, O corresponds to the shaft D, Fig. 3; Oa, to the piston crank K; and Ob, to the valve crank k. The larger circle of dotted lines represents the path of the center of the piston crankpin as it revolves around the shaft O, and the smaller circle represents the path of the center of the valve crankpin. ac corresponds to the

*The irregular displacement of the valve and piston, due to the angularity of the valve rod and connecting-rod, will not be considered in this Section.

Boiler.




S
T
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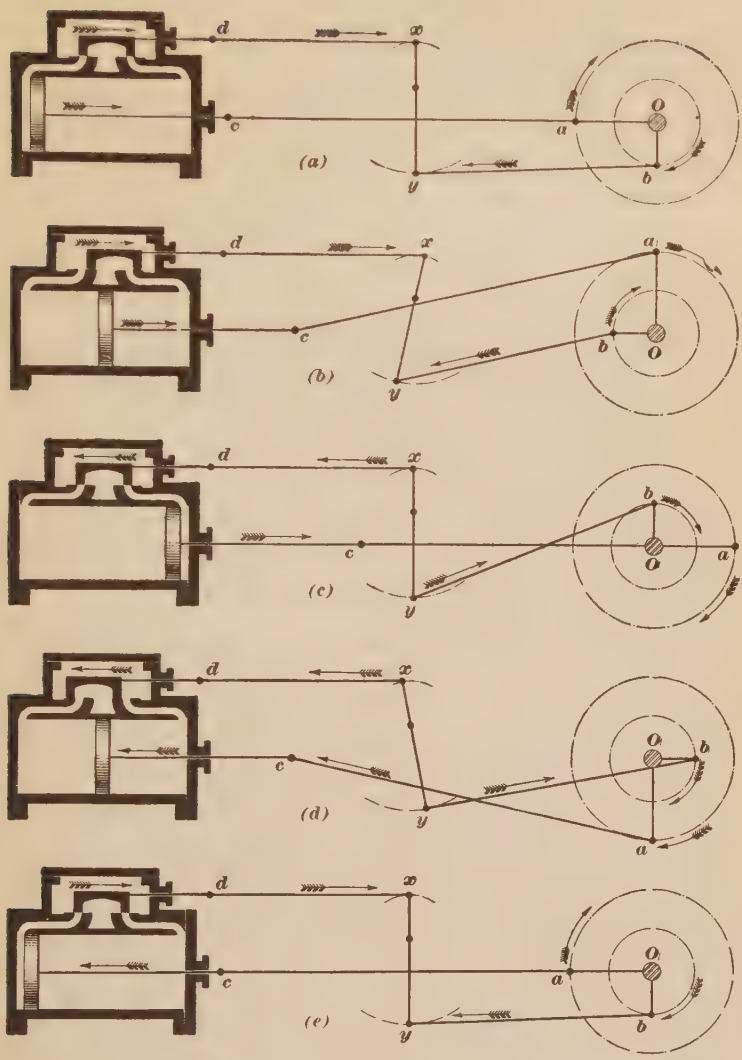

FIG. 4

connecting-rod, and $d.x$ to the valve rod; xy is a rocker. Some of the parts have been exaggerated to make the diagrams clearer.

Diagram (*a*).—The diagram (*a*) represents the piston at the end of its stroke and just about to move to the right, as shown by the arrow. Also, the valve is about to move in the direction of its arrow, and therefore steam is about to be admitted to the left-hand steam port, while the right-hand port is about to be connected with the exhaust. The piston is at the beginning of its backward stroke, while the valve is at mid-stroke. It will be noticed that with the piston in this position, the connecting-rod ac and piston crank Oa form a straight line, while the valve crank, which is at right angles to it, is vertical. All the parts are about to move in the direction indicated by their arrows.

Diagram (*b*).—Diagram (*b*) shows the position of the parts when the crank Oa has moved through the first quarter of its revolution, and is at right angles to its position in diagram (*a*). While the crank is moving through this quarter circle, the piston moves from the beginning to the middle of its stroke, and the slide valve moves from the middle to the end of its backward stroke, and is on the point of reversing its motion. The left steam port is now wide open for the admission of steam, and the right steam port is wide open for exhaust.

Diagram (*c*).—Diagram (*c*) shows the position of the parts when the crank has moved through the second quarter of its circle. The piston has moved from mid-stroke to the end of its backward stroke, and is on the point of reversing the direction of its motion. The slide valve has reversed the direction of its motion, and traveled from the beginning to the middle of its forward stroke; consequently, it has just closed both steam ports and is on the point of opening the right steam port for the admission of steam, and the left port for the flow of exhaust steam to the atmosphere.

Diagram (*d*).—As the crank travels its third quarter, to the position shown in diagram (*d*), the piston has its

direction of motion reversed and travels the first half of its forward stroke. The slide valve, during the same time, has traveled from the middle to the end of its forward stroke. In this position both steam ports are wide open—the right-hand one to the steam chest, and the left-hand one to the exhaust.

Diagram (*c*).—While the crank travels the last quarter of its stroke, to the position shown in diagram (*c*), which is the same as that shown in diagram (*a*), the piston travels the last half of its forward stroke, and is on the point of reversing and beginning another backward stroke. The valve, meanwhile, has traveled from the beginning to the middle of another backward stroke and again covers both steam ports. Since the valve is moving backwards, it is on the point of uncovering the left steam port for the admission of steam and connecting the right steam port with the exhaust.

10. Comparison of Diagrams.—Comparing the directions of the arrows, which indicate the direction of the motion of the different parts in the five diagrams, it will be seen that the slide valve is always half a stroke ahead of the piston. During the first half of the backward stroke of the piston, the valve and piston move in the same direction, but during the last half the valve moves to the left, while the piston continues to the right. The left steam port, therefore, is open for the admission of steam, and the right port to the exhaust, for the full length of the backward stroke. Likewise, during the first half of the forward stroke, the valve and the piston travel in the same direction, whereas, during the second half, they travel in opposite directions. During the full length of the forward stroke, steam is admitted to the right of the piston, while the space to the left is open to the exhaust.

Another thing to notice is that when the crank *O a* and the connecting-rod *a c* are in the same straight line, as in diagrams (*a*), (*c*), and (*e*), the piston is at the end of its stroke. When in this position, the engine is said to be **on the dead center.**

In practice, it is not customary to admit steam to the cylinder for the full length of the stroke. Steam is admitted during a part of the stroke only; the supply is then cut off and the steam in the cylinder allowed to expand during the remainder of the stroke. This subject, however, will be more fully discussed later.

LOCOMOTIVES

11. Classification.—The system of classification of locomotives adopted generally by railroads and locomotive manufacturers, and the one that we shall employ, is known as the **Whyte system,** after its inventor, Mr. F. M. Whyte. Until recently, no general system was used, and the result is that engines of the same type, but built by different manufacturers, are called by different names, which would lead one to believe they were engines of entirely different types. For example, Atlantic, Northwestern, and Chautauqua engines belong to the same type and differ only in details of construction. It was in order to avoid this confusion of types that the present system was invented. The Whyte system classifies locomotives according to their wheel arrangement. It does not take into consideration modifications of trailer trucks, fireboxes, position of cabs, etc., but deals strictly with the wheel arrangement.

The American eight-wheel engine, by this system, is known as the 4–4–0 type; the first figure signifies that the engine has a four-wheel truck, the second that there are four drivers, and the last that there is no trailer truck. Any locomotive with a four-wheel truck, four drivers, and a two-wheel trailer truck is designated as a 4–4–2 type engine. A mogul is a 2–6–0 type, as it has a pony truck, six drivers, and no trailer wheels. A ten-wheel engine is a 4–6–0 type, as it has a four-wheel truck, six drivers, and no trailer wheels, and so on for the other types. The operation of this system of classification will be seen by comparing the types of locomotives that will now be described.

1. *4–2–2, or Bicycle Type.*—This type of engine, shown in Fig. 5, has a four-wheel truck, one pair of drivers, and a pair

of carrying or trailing wheels under the firebox. It is specially designed for fast passenger service with light trains.

2. *4–4–0, or Eight-Wheel American Standard Type.*—This engine, Fig. 6, has a four-wheel truck and four drivers. It is very successful in handling trains of moderate weight.

Fig. 5

3. *2–4–2, or Columbia Type.*—This type of engine, Fig. 7, was designed to handle heavy passenger trains at high speed. It has a pony truck with two truck wheels, four drivers, and a pair of trailing wheels under the firebox.

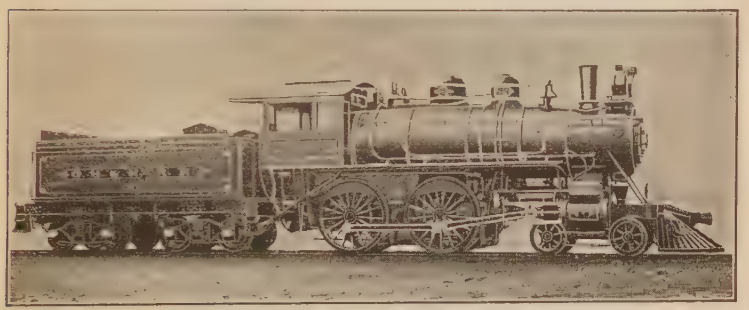

Fig. 6

4. *4–4–2, or Atlantic Type.*—An *Atlantic* type engine, Fig. 8, has a four-wheel truck, four drivers, and a pair of trailing wheels under the firebox. This type is designed to handle heavy passenger trains at high speeds. With this

design of Atlantic type engines, the trailer journal-boxes, equalizers, and springs are inside the trailer wheels, and the engine frame is straight. This engine is also known as a *Chautauqua* type, the trailer journal-boxes of which are

Fig. 7

designed to give a radial motion to the axle and the wheels to shorten the rigid wheel base and allow the engine to curve easily.

Another design of Atlantic type is shown in Fig. 9. The boiler has a wide firebox, and the engineer's cab is located ahead of the firebox.

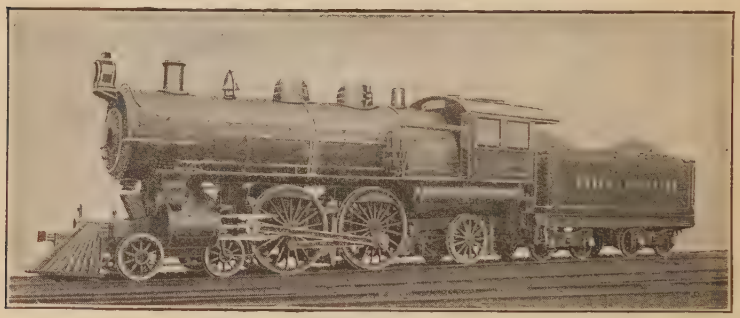

Fig. 8

The *Northwestern*, or *Central Atlantic*, type of engine, Fig. 10, has a supplemental frame for the back end of the engine outside the main frame; so that the back end of the frame, truck boxes, and springs are outside the trailer wheels.

FIG. 9

FIG. 10

FIG. 11

This gives a more convenient location of the journals of the trailer wheels.

5. *4–6–0, or Ten-Wheel Type.*—This is a common type of engine, Fig. 11, having a four-wheel truck and six drivers.

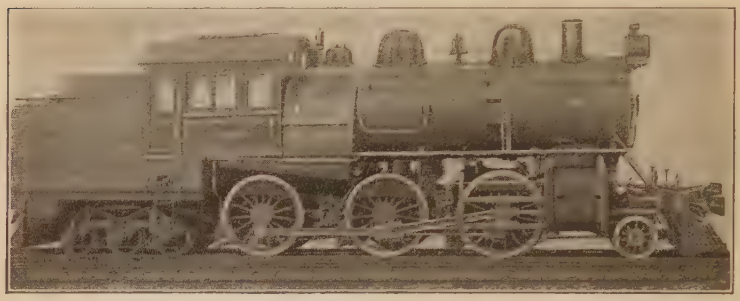

Fig. 12

It is very successful in both passenger and freight service with fast trains, unless the conditions are very severe.

6. *2–6–6, or Suburban Type.*—This type of engine, Fig. 12, is designed for heavy trains doing local work, making many stops. It has a capacity for starting trains and bringing

Fig. 13

them up to a fast speed quickly. It has a two-wheel truck, six drivers, and a six-wheel truck under the tender. The frame is continuous from one end of the locomotive to the other. They are built to run equally well forwards or backwards.

7. *2–6–0, or Mogul Type.*—This type of engine, Fig. 13, has a two-wheel pony, or Bissell, truck equalized with the forward pair of drivers, and six drivers. This engine was originally designed for heavy freight service; it is now used in passenger service and for ordinary freight service.

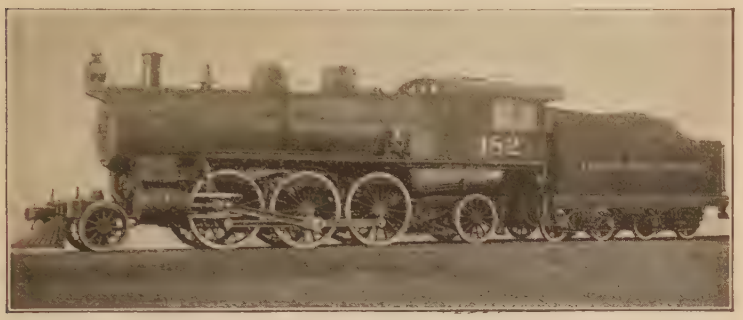

Fig. 14

8. *2–6–2, or Prairie Type.*—This type, Fig. 14, has a two-wheel pony truck, six drivers, and a pair of trailing wheels under the firebox. They are used in both heavy passenger and freight service, having immense boiler power.

Fig. 15

9. *4–6–2, or Mountain Type.*—This engine, Fig. 15, has a four-wheel truck, six drivers, and one pair of trailing wheels under the firebox; it is also known as the *St. Paul*, or *Pacific*, type.

10. *2–8–0, or Consolidation Type.*—This engine, Fig. 16, has a two-wheel truck and four pair of drivers. It was designed, many years ago, for heavy freight service and is still used for that purpose.

Fig. 16

11. *2–10–0, or Decapod Type.*—This engine, Fig. 17, is like a consolidation, except that it has five pair of drivers. The truck has two wheels.

12. *4–8–0, or Twelve-Wheel Type.*—A twelve-wheel engine, Fig. 18, has a four-wheel truck and eight drivers.

Fig. 17

13. *2–8–2, or Micado Type.*—The *Micado*, or *Calumet*, type, Fig. 19, has a two-wheel truck, eight drivers, and a pair of trailing wheels under the firebox.

14. *0–4–0, or Four-Wheel Switcher.*—This engine, Fig. 20,

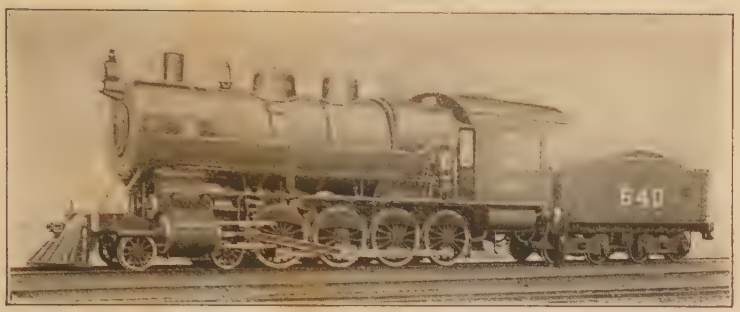

FIG. 18

FIG. 19

FIG. 20

has four drivers but no truck wheels, so that all the weight is carried by the drivers. Some of these engines have a saddle tank on the boiler for the supply of water and carry the coal in small bunkers in the end of the cab.

FIG. 21

15. *0–6–0, or Six-Wheel Switcher.*—This engine, Fig. 21, has six drivers and no truck wheels.

16. *0–8–0, or Eight-Wheel Switcher.*—A larger type of switch engine having eight drivers is shown in Fig. 22; it is

FIG. 22

the most powerful engine designed exclusively for switching service.

12. Number of Drivers.—By increasing the number of driving wheels, larger and heavier engines can be used and a greater percentage of the weight of the engine can be

carried on the drivers, thereby greatly increasing the traction of the driving wheels on the rails without, at the same time, imposing excessive pressure on the driving axles or on the rails at one place.

One disadvantage of increasing the number of pairs of drivers is that it increases the length of the rigid wheel base and thus tends to make the engine curve hard. The advantages of using more than two pair of drivers are so much greater than the disadvantages, however, that the practice of coupling three or more pair of drivers together has become standard.

13. Wheel Base.—The **rigid wheel base** of a locomotive without a trailing wheel is the distance between the centers of the first and last driving axles. The rigid wheel base of engines having trailing wheel usually includes the rear, or trailing, pair of wheels; these wheels as a rule, however, are given more play than the drivers.

The **total wheel base** is the horizontal distance between the centers of the axles of the first truck wheel and the last driving wheel—or, in Figs. 14 and 15, the pair of trailing wheels. With some engines, like the Chautauqua type, the trailer is designed to give a lateral motion that shortens the rigid wheel base.

In speaking of drivers, the pair toward the front end is called the first pair; immediately back of these is the second pair; etc.

14. Gauge of Track.—The gauge of a track is the distance between the two rails, measured on the inside, as

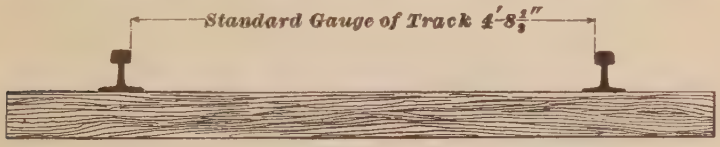

FIG. 23

shown in Fig. 23. The standard broad gauge is 4 feet 8½ inches; for narrow-gauge railways, the gauge varies from 21 inches to 3 feet.

FRAMES

15. General Description.—The **frame** forms a carriage for, and therefore carries the weight of, the other parts of the locomotive. Side views of four styles of frames in common use are shown in Fig. 24. Frames (*a*), (*b*), and (*c*) are made in two parts. The cylinders are fastened to the front part, or rail, of the frame, which is called the *splice*. The back part, called the *main frame*, contains the *pedestals* or jaws for the driving boxes. (*a*) represents the frame of an eight-wheel passenger engine; (*b*), that of a ten-wheel engine, or with cylinder connection like that of (*c*), a mogul; (*c*), that of a consolidation engine; (*d*) is for the same class of engine as (*c*), but differs from the latter in the mode of construction, the lower frame braces being bolted to the frame legs instead of being solid therewith.

The jaws, or pedestals, hold the journal-boxes in place, and consist of two frame legs each. In views (*a*), (*b*), and (*c*), these are welded to the top rail and lower frame braces of the main frame, thus binding them together.

Different styles of pedestals are shown in Figs. 25, 26, and 27. *A* is the top rail of main frame; *B*, *B* are the frame legs that form the jaws; and *C*, in the case of Fig. 25, is a *pedestal cap*, or binder, which is bolted to the lower frame brace *D*. The pedestal cap binds the frame legs together and prevents their spreading, while at the same time it permits the wheels and boxes to be readily dropped out or put in when necessary.

In Figs. 26 and 27, the frame legs are bound together at the bottom by the jaw bolt *E*, which passes through the *frame thimble C* inserted between the legs of the jaw. The jaw bolts are generally 2 to $2\frac{1}{2}$ inches in diameter. The frame thimble is made of cast iron, and is provided at one end with slots *F*, *F* through which the wedge bolts *G* pass. The thimble arrangement is generally used for larger engines, since on engines having small cylinders and small frames the jaw bolts interfere with the wedge bolts; pedestal caps, therefore, are preferable for small engines.

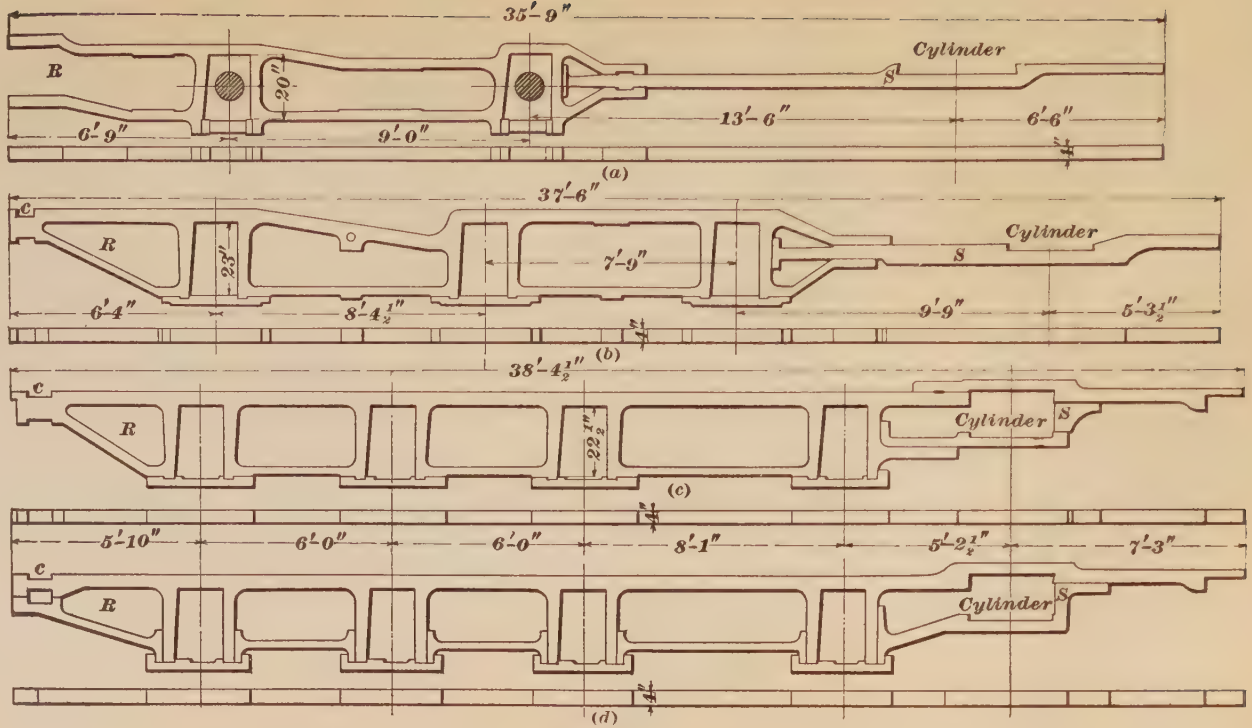
35′-9″
R
20″
Cylinder
S
6′-9″
9′-0″
13′-6″
6′-6″
4″
(a)
37′-6″
C
R
23″
7′-9″
Cylinder
S
6′-4″
8′-4½″
9′-9″
5′-3½″
4″
(b)
38′-4½″
C
R
22½″
Cylinder
S
(c)
4″
5′-10″
6′-0″
6′-0″
8′-1″
5′-2½″
7′-3″
C
R
Cylinder
S
4″
(d)

FIG. 24

Two forms of jaw are used. That shown in Figs. 26 and 27 has one straight and one tapered leg. The straight leg is usually placed nearest the cylinders, as it is then easier to maintain the same distance between the center of the cylinder and of the driving axles. In Fig. 25 both legs of the jaw are tapered. This form has been extensively used, but of late years that shown in Figs. 26 and 27 has had the preference. In both forms the taper of the legs is usually $1\frac{1}{8}$ inches in 12 inches.

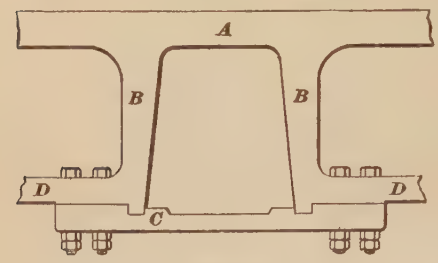

FIG. 25

16. Wedges and Shoes.—The **wedge** W_2 and **shoe** W_1, Figs. 26 and 27, serve two purposes: first, they protect the legs from wear; and, second, they provide a means of taking

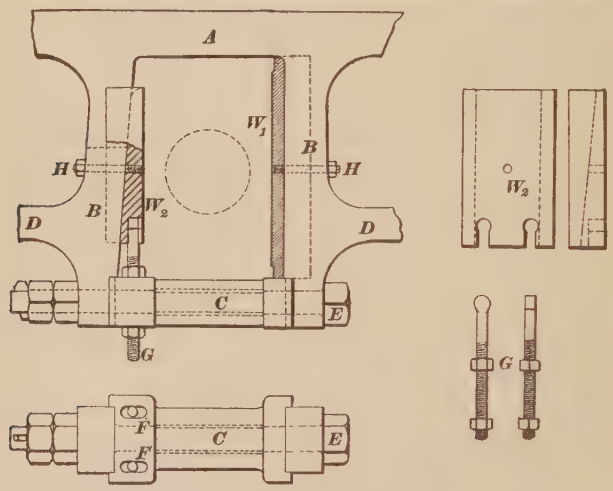

FIG. 26

up any play between the journal-box and wedges that may result from wear. When the engine is in motion, the journal-boxes play up and down in their pedestal jaws, and

gradually wear away the wedge and shoe. If this wear is not taken up, it soon results in a bad pound, which occurs every time the engine passes a dead center.

17. Taking up the Play.—The play is taken up by moving the wedge W_2 upwards by means of the wedge bolts G, since raising the wedge brings its face and that of the shoe nearer together. The bolts H, H hold the wedge and shoe in position against the legs of the jaw; and, since the wedge W_2 must be raised, a slot is cut in the tapered leg

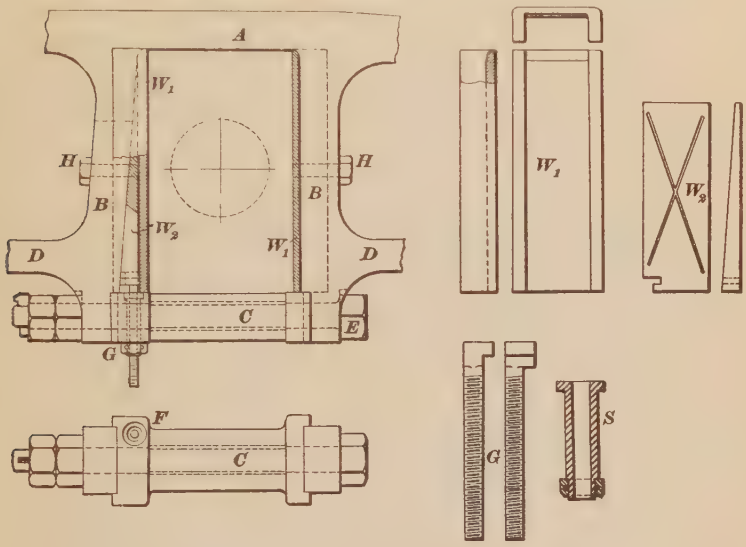

FIG. 27

of the jaw, which permits the bolt, when loosened, to be moved up or down with the wedge while the latter is being adjusted. To raise the wedge, therefore, the bolt H must be slacked out to permit it to move up with the wedge, and the lower nut on the wedge bolt G must be unscrewed sufficiently, after which the wedge may be raised by turning the upper nut of the wedge bolt in a direction that will raise it. When the wedge is properly adjusted, the lower wedge-bolt nut and the bolt H should be tightened. Very few new engines have bolts H.

The head of the wedge bolt G fits into the slot at the bottom of the wedge W_2. The wedge, therefore, may be lowered by loosening the bolt H and unscrewing the upper, and screwing up the lower, wedge-bolt nut.

18. Live and Dead Wedges.—The wedge W_2 is sometimes called the **live wedge,** and the shoe W_1 the **dead wedge,** the former having the same taper as the pedestal leg, so that the faces of the shoe and wedge are parallel to each other and at right angles or "square" with the edge of the top rail A.

In some cases, the jaws are fitted with one live and one dead wedge, as in Fig. 26; in others, with one live and two dead wedges, as in Fig. 27—the latter construction being used for high-speed passenger engines—while with pedestals like that of Fig. 25, two live wedges are used.

19. Attaching Boiler to Frames.—Across the front ends of the frame splices is a beam called the *buffer beam*. This is bolted to the splices, and to this beam are fastened the pilot and coupler. The boiler is rigidly attached to the cylinder saddle, and the splices are rigidly fastened to the cylinders. The splices are usually supplied with lugs to which the cylinders are secured by means of wedges and bolts. The portions of the splices that extend beyond the cylinders and are secured to the buffer beam, are fastened to the smokebox with two diagonal iron braces called *arch braces*, and, as a rule, are stayed together by a transverse brace of iron or steel. Connection is made between the barrel of the boiler and the frames by braces, and between the firebox and frames by expansion plates. When heated, the boiler expands and lengthens from $\frac{1}{4}$ to $\frac{5}{16}$ inch more than the frames. The expansion clamps, therefore, must be so constructed that while they secure the firebox to the frames they will allow it to move relative to the latter as the boiler expands, thus avoiding the strains to which both the firebox and frames would otherwise be subjected. The back ends of the frames are held together by the tail-piece and foot-plate. The boiler is sometimes connected to the

guide yoke, which is bolted to the frames. The upper part of the frames is held together by one or more transverse braces. That part of the frame under the foot-plate is usually fastened to the back boiler head by means of diagonal braces, called expansion braces.

SPRING ARRANGEMENT

20. General Description.—Fig. 28 shows how the weight of the locomotive is transferred to the journals of the driving axles on an eight-wheel engine. In the figure, the axles are supposed to be cut off just back of the nearest drivers, which are removed to give a better view of the arrangement of the parts. The arrangement of the gear on

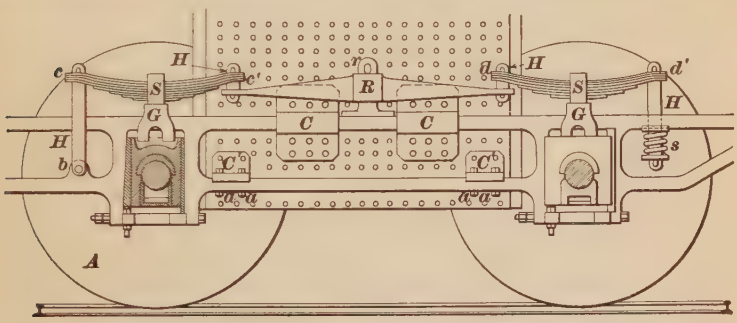

FIG. 28

the other side of the engine is, of course, similar to that shown in the figure.

The weight of the frame and its load rests on the axle journals just inside the driving wheels. These journals turn in journal brasses, or bearings, in the driving box, the box being held in position by jaws and wedges. In the figure, *A* represents the off-side drivers; *C* and *C'*, the expansion plates that connect the firebox and frame together, the bolt holes for *a* being elongated; *G*, the spring saddles, which rest on top of the driving boxes; *H*, the spring hangers, the hanger to the left being attached to the frame at *b* with a pin. The hanger to the extreme right passes through the upper

frame brace and a spiral spring s. The short hangers connect the ends of the equalizer R to the driving springs as shown. The fulcrum r of the equalizer is securely bolted to the frame. S, S are spring bands that hold the leaves of the driving springs in place. An inspection of the figure will show that the weight sustained by the frame is transferred to the springs, and thence through the spring saddle and journal-box to the journals of the driving axles.

The duty of the springs is to absorb or take up the shock occasioned every time the drivers pass over a bad rail joint, or a high or low spot in the track. By "giving" somewhat, the springs transform what otherwise would be a sudden blow into a gradually increasing pressure that is not nearly so destructive to either track or locomotive.

21. Duty of Equalizer.—The duty of the **equalizer** R is to distribute and maintain the weight equally on all the driving wheels. If no such device were used, and if the frames were supported directly on the driving boxes, every time a driver went over a high spot it would tend to lift and carry the load of the other drivers on that side; also, every time it dropped into a low spot it would tend to throw its share of the load on the other drivers. This not only would make the engine ride hard, roll, and pitch more than usual, but it would subject the whole engine to such stresses as would necessitate more frequent repairs and renewals.

22. Mode of Operation of Equalizing Gear.—The manner in which the equalizing gear maintains the load on the drivers equal is as follows: When the driver A rolls on to a high spot in the track, its axle and, therefore, the saddle G are raised. This tends to move the spring upwards, but as the end c cannot move up—being attached to the frame at b by the hanger H—only the end c' moves upwards. This movement causes the equalizer to rotate on the fulcrum r, the end c' moving upwards, while the other end, which is attached to the second driving spring at d, is moved downwards, carrying that end of the second spring with it.

Thus, since the end d' of the spring is prevented from moving upwards, a downward pressure is transferred through the saddle G to the axle of the second driver, and both springs are made to bear the shock instead of all being borne by one.

DRIVING WHEELS

23. Axles.—Axles are designated according to their use as *driving*, *front truck*, *trailing*, and *tender axles*. They are made of wrought iron or steel and are designated according to their manufacture as *hammered*, *muck bar axles*, or *fagoted*. In Fig. 29 are shown three styles used in locomotive practice.

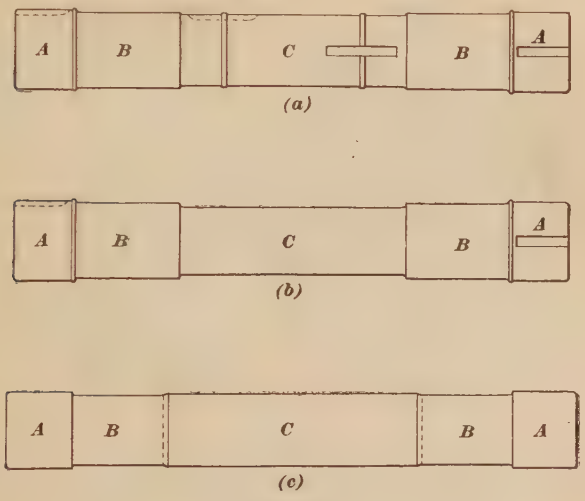

FIG. 29

The part A is called the *wheel fit*, and the part B, the *journal*. The central part C of the axles is smooth-forged.

Axle (a) is used as a main driving axle. Axle (b) is used for trailing-truck axles, and, as shown, the central part C is reduced in diameter. Axle (c) also is a driving axle, but for a consolidation locomotive.

24. Wheel Centers.—Examples of driving wheels are shown in Figs. 30 to 33. They consist of the **wheel**

center A on which is shrunk a tire B, Fig. 30. The driving-wheel centers have in the past been almost universally made of cast iron, but now steel castings are used. Sometimes the spokes S are cast solid, but usually they and the rim D are cast hollow, in the case of cast-iron centers. The hub H, the crank E, and the counterbalance C complete the driver. The counterbalance is either cast in segments and bolted between the spokes, as in Fig. 31, or it is cast together with the wheel, either hollow as in Fig. 30, or solid as in Figs. 32 and 33. When cast hollow, lead is afterwards run in through the core holes.

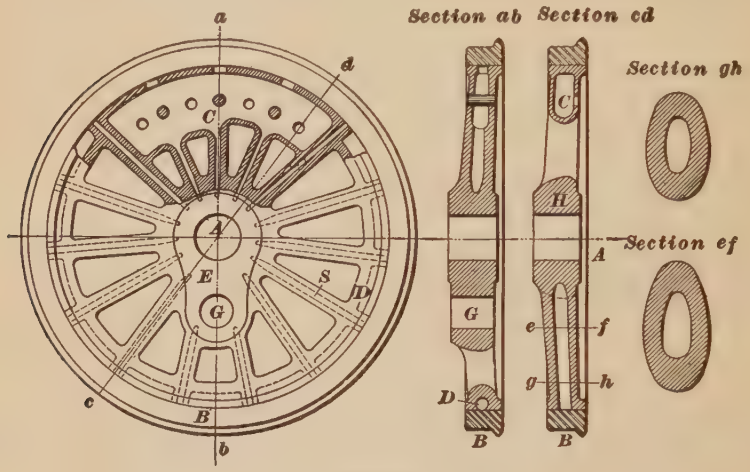

Fig. 30

The tires are shrunk on their centers. The wheel centers are turned as shown in section bc, Fig. 31, and the tire is bored somewhat smaller in diameter than that of the wheel center. The tire is then heated by means of a number of gas flames arranged in a circle, until it is sufficiently expanded to slip over the wheel center. After having put the tire in place it is cooled, thus causing it to contract and bind on the center.

Eight-Wheel Engines.—The wheel shown in Fig. 30 is the one most commonly used for eight-wheel passenger locomotives. In this wheel the rim, spokes, and counterbalance

are cast hollow. The drawing on the right represents the halves of two wheels, the left-hand half representing in part elevation and part section the half of a main driver, while the right-hand half is a similar representation of half of a rear driver, the difference between the two being in the dimensions of the counterbalance. Immediately to the right of this drawing is a section of the main driver, taken on the line *a b*, while to the right of that is a section of the back driver, taken on the line *c d*. The spokes are of an oval shape and are cast hollow, as shown by the sectional views,

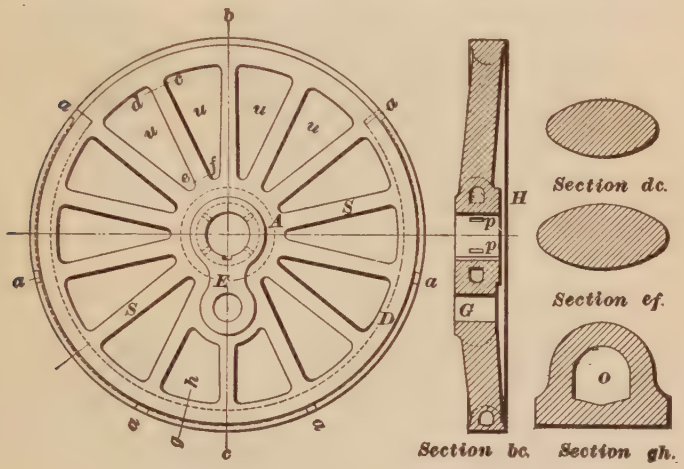

FIG. 31

taken on the lines *b c* and *g h*. These forms are the most economical for resisting the stresses and saving material.

In Fig. 31 is illustrated the wheel center of a main driver for a high-speed passenger engine. In this wheel the spokes are cast solid, but the rim is hollow, except the upper portion *a b a*. The cored part *o* of the rim does not extend to the outside (see section *g h*), and the only openings in it are the core holes *a*. The hub *H* of the wheel center is also cored, leaving openings *p* on the inner surface. Solid blocks of iron, which form the counterbalance, are placed between the spokes at *u*, and bolted or riveted in place.

Fig. 32 shows another style of main driver for a standard eight-wheel engine. This wheel is cast entirely solid, but the rim is slit at *a*, *b*, and *c*, to avoid the stresses due to

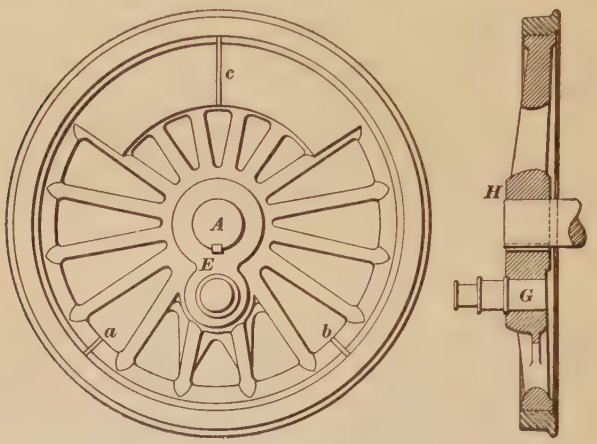

FIG. 32

shrinkage when the casting cools. Nearly all wheel rims are thus slit. Liners are inserted in these slits, and the tire is then shrunk on the center, as before described.

Consolidation Engine.—In Fig. 33 is shown the wheel center of the main driver for a consolidation engine. The spokes and counterbalance are cast solid, while the rim is cored out, leaving openings *a* on the outer surface of the wheel center for the core holes. These wheels are generally small in diameter, and if the counterbalance is not sufficiently heavy to meet the requirements, it is cast hollow, leaving closed chambers between the spokes, which are then filled with lead to increase the weight of the counterbalance.

25. Tires.—The drivers have **flanged tires,** and vary from $4\frac{3}{4}$ to $6\frac{1}{4}$ inches in width, according to specifications.

In 1893, the Master Mechanics' Association adopted the following sizes as standard for large driving wheels centers. 70, 74, 78, 82, 86, and 90 inches. In 1896, the Association adopted as standard practice a minimum thickness of 1 inch

for the flanges of engine and truck wheels, the thickness to be determined by the M. C. B. flange-thickness gauge.

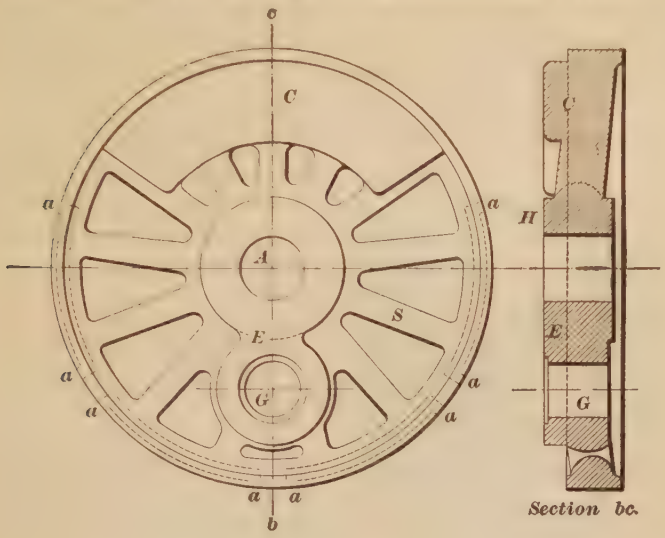

FIG. 33

In Fig. 34 is shown a sectional view of a tire; *a* is the width; *b*, the depth; *c*, the height of the flange; and *d*, the clearance for the rail, which is a fillet having a radius of $\frac{9}{16}$ or $\frac{5}{8}$ inch.

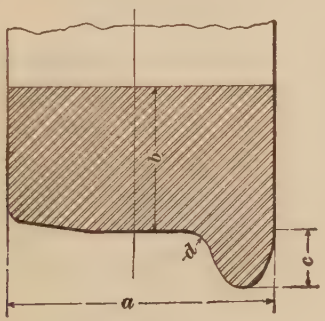

FIG. 34

26. Driving Box.—Fig. 35 shows a **driving box.** The driving boxes and truck boxes transfer the entire

weight of the engine (less the weight of the wheels and axles, side rods, and back end of main rod) to the journals. *A* is the driving box, and *B* the oil cellar, which is filled with oil-soaked waste that keeps the bearings well lubricated. The cellar is kept in position by the pins *d*, *d*. The flanges *f*, *f* serve to retain the driving box in place, the jaws and wedges fitting between the flanges. The rectangular-shaped holes *e*, *e* receive the legs of the spring saddle. *C* is the driving-box brass, or journal bearing.

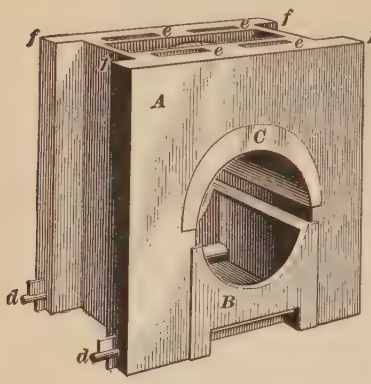

FIG. 35

SETTING UP THE WEDGES

27. When Steam Is Up.—In setting up wedges, the idea is to take up all lost motion between the driving box and the wedges, leaving just sufficient freedom to allow the driving box to move up and down freely in the jaws, and to allow for expansion should the box become heated. Wedges can best be set up when the engine has steam up, although they can also be set up when the engine is cold.

Place the engine on a piece of straight, level track. Place the right crankpin on the top forward eighth. The left crankpin will then be on the top back eighth. Block the engine truck. Place the reverse lever in full forward gear, and admit a little steam into the back end of the cylinder. This will pull all the driving boxes forwards against the shoes, leaving all the play next to the wedges, when they can be readily taken up by raising the wedge W_2, Figs. 26 and 27, with a short bar. The wedge should be pinched up solid and then drawn down from $\frac{1}{16}$ to $\frac{1}{8}$ inch. The locknuts on the wedge bolts, and the bolts that secure the wedges to the pedestal jaws, should then be screwed up tight.

To set up the wedges on the left-hand side, place the crankpin of that side on the top quarter; then proceed as with the right-hand wedges.

28. When Engine Is Cold.— If the wedges must be set up without the aid of steam in the cylinders, proceed as follows: Place the engine on a straight, level track, as before, with the crankpin on the top quarter; block the drivers on the opposite side, and use a bar behind the drivers, on the side on which you are working, to pinch the driving boxes forwards against the shoes. The wedges are then set up as in the other method.

ENGINE TRUCKS

29. Two styles of locomotive trucks are used—the four-wheel and the two-wheel. The truck wheels used are from 28 to 36 inches in diameter, depending on their location, the size of the cylinders, and the amount of clearance for the wheels. High-speed engines with large driving wheels give more clearance under the cylinders than engines with smaller driving wheels; consequently, larger truck wheels can be used.

30. Four-Wheel Truck.—A four-wheel truck, or an independent truck, is shown in Fig. 36. The frame *F* is riveted or bolted to the transverse bars *T*, which support

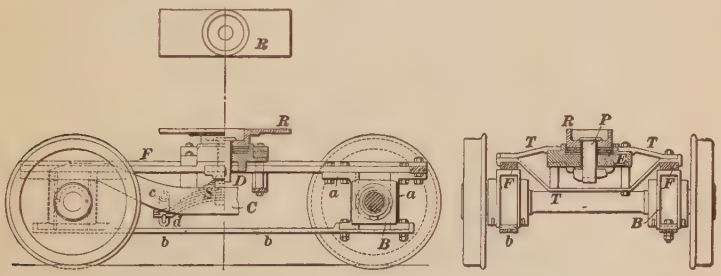

FIG. 36

the center casting *E*. The center casting contains three or four liners, on which the center plate *R* rests. The center

casting and the center plate are connected by the center pin *P*. To the frames are bolted the cast-iron or wrought-iron jaws *a*, *a* that form a jaw for the truck box *B*, which is made of iron, and is quite similar to a driving box, except that no wedge and shoe are used in connection with it. The lower parts of the jaws are held together by longitudinal braces *b*, one on each side of the truck. The frame rests on the spring bands *D*, and so is carried by the springs *S* (one on each side). The truck boxes are provided with recesses in the top part for retaining the equalizer *C* in place. The springs are connected to equalizers by the hangers *d*, which swing on pins *c*.

The half-elliptic spring shown has of late been replaced, to a certain extent, by spiral springs when the trucks are the two-wheel type. The length of the truck wheel base (the distance between the center lines of the axles) must, however, be great enough to allow the wheels to clear the cylinder heads when the engine is passing around a curve.

The truck-wheel guards are generally fastened on the splice of the engine frame or to the truck frame. When the latter method is used, care must be taken that they clear the frame when the truck swings.

Four-wheel trucks are used under eight-, ten-, and twelve-wheeled engines.

31. Two-Wheel Truck.—Fig. 37 shows a two-wheel truck in plan, sectional elevation, and cross-section. This is commonly called the **pony,** or **Bissell, truck,** and is used under mogul and consolidation engines.

The frame *F Q Q' F'* is of rectangular shape, and to it the jaw is attached. A **V**-shaped frame *S*, the *radius bar*, is bolted to the rectangular frame by the bolts *l*. The radius bar extends back under the engine, and is connected to the main frame by a crosspiece or bar (not shown), and pin *L*. This allows the truck to swing laterally about the pin, thus adjusting itself to the curves of the track. The bedplate of the cylinders rests on the casting *R*, which is connected to the equalizing lever *M N* by the pin *K*. This lever supports

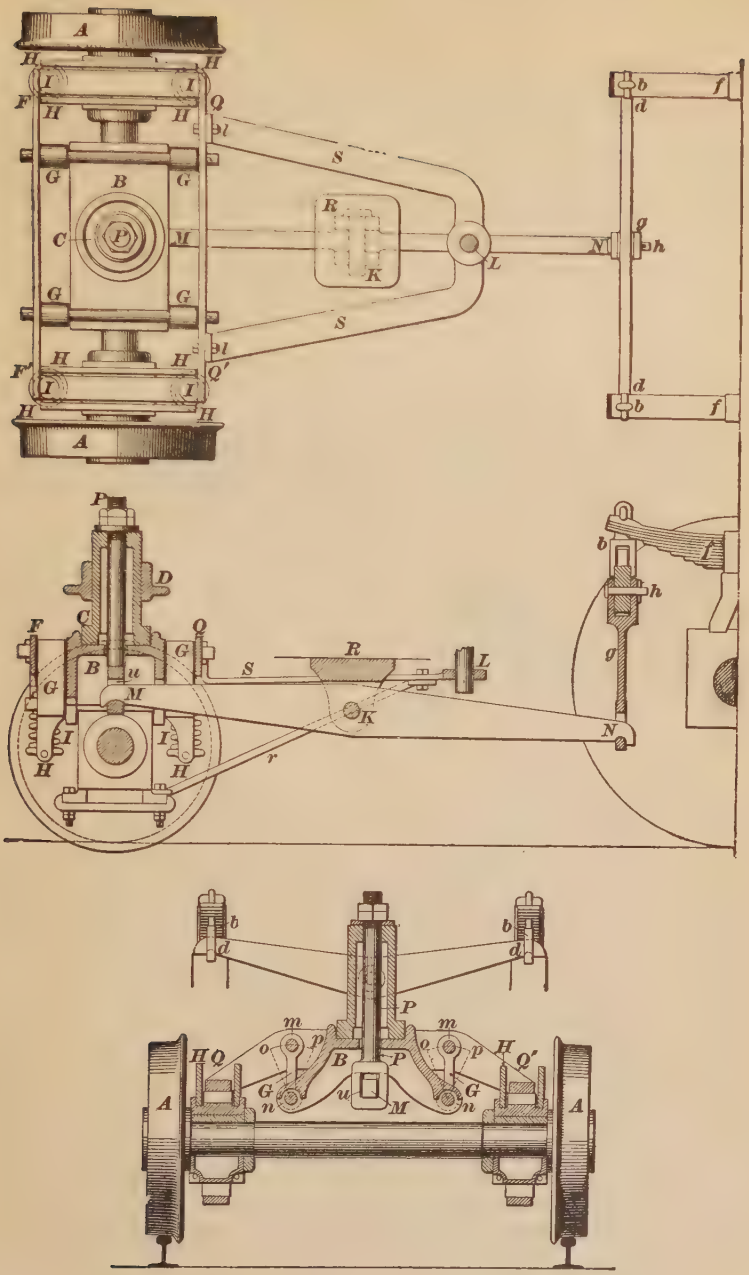

FIG. 37

the weight of the front end of the engine in the following manner: The back end N is connected to the hanger g as shown. The upper end of the hanger is attached to the transverse equalizing lever d, d by the pin h, this lever being in turn connected by the hangers b, b to the front ends of the forward driving springs f, f. The other end M of the equalizing lever passes through the slot u of the bolt P, which is sustained by the hollow kingbolt C. The kingbolt is placed inside the casting D, which is bolted to the engine frame, and rests on the casting B (the *bolster*) which is carried by the links G, G, suspended from the truck frame $F\,Q\,Q'\,F'$ in the manner shown, the connection being made by means of the pins m, n. A bolster that is suspended in this manner is called a "swing bolster." The truck itself is carried on

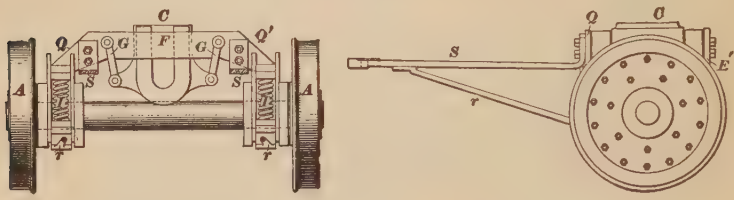

FIG. 38

spiral springs I, I; yokes H, H shaped something like an inverted **U** rest on top of the boxes, and their lower ends carry castings in which sit the springs I, I. r is the pedestal brace. The remaining details should be evident from the figure.

This form of pony truck relieves the engine of a large portion of the jars and shocks due to irregularities in the track. For, suppose that there was a slight depression in the track, the truck on reaching it would go suddenly downwards, and the sudden stoppage would produce a shock. With the truck described, the pin K acts as a fulcrum, the end M of the equalizing lever going down, and the end N going up; then, as the front end of the engine comes down, the springs f are bent, causing the front end to descend very gradually, the springs absorbing the shock.

The links G, G permit the engine to pass more easily around a curve. Thus, suppose that the engine meets a curve: the engine tends to keep straight ahead, while the flanges of the wheels A, A compel the truck to follow the curve. The consequence is that the entire truck, together with the bolster, is swung laterally to the right or left, according to the character of the curve, the links G, G swinging to the position $o\,n$ or $p\,n$, and the radius bar turning about its pin L.

Another form of pony truck is shown in Fig. 38. Here there is no equalizing lever, the radius bar being bolted to a cross-piece that is attached directly to the main frame. The construction should be evident from the cut. The kingbolt fits in a hole at C, and connects the bedplate directly to the swing bolster. The other parts are lettered the same as in Fig. 37.

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NOTE.—In this volume, each Section is complete in itself and has a number. This number is printed at the top of every page of the Section, in the headline opposite the page number, and to distinguish the Section number from the page number, the Section number is preceded by a Section mark (§). In order to find a reference, glance along the inside edges of the headlines until the desired Section number is found, then along the page numbers of that Section until the desired page is found. Thus, to find the reference "Air, §10, p47," turn to the Section marked §10, then to page 47 of that Section.

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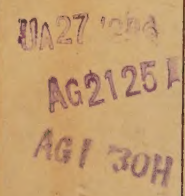

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